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ELECTROSTATIC CHUCK HAVING IMPROVED GAS CONDUITS

Abstract:

Abstract of WO 9925006

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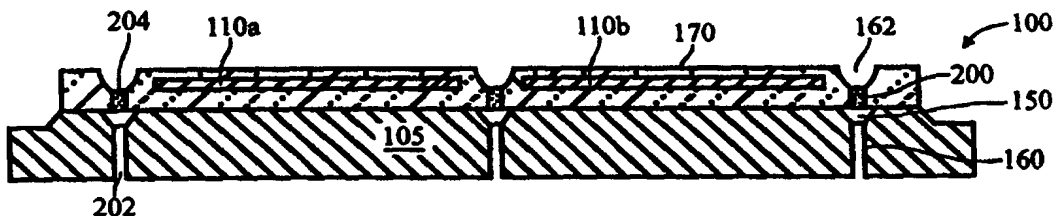
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An electrostatic chuck (100) useful for holding a substrate (55) in a high density plasma, comprises a dielectric covered electrode (110) having at least one heat transfer gas flow conduit (150) therein. An electrical isolator (200) comprising dielectric material is positioned in the gas flow conduit (150) to (i) electrically isolate the gas in the conduit from the plasma or electrode (110), and (ii) allow passage of heat transfer gas through the conduit. Preferably, the dielectric material comprises a plasma-deactivating material that has a high surface area that reduces plasma formation of gas passing through the conduit (150) in a plasma process.

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ELECTROSTATIC CHUCK HAVING IMPROVED GAS CONDUITS

CROSS-REFERENCE

5 This application is a continuation-in-part of U.S. Patent Application Serial No. 08/639,596, filed on April 26, 1996, entitled, "Conduits for Flow of Heat Transfer Fluid to the Surface of an Electrostatic Chuck," by Weldon et al., which is incorporated herein by reference.

10 BACKGROUND

 The present invention relates to an electrostatic chuck for holding substrates in a process chamber.

15 Electrostatic chucks are used to hold substrates in various applications, including for example, holding a silicon wafer in a process chamber during semiconductor fabrication. A typical electrostatic chuck comprises an electrode covered by an insulator or dielectric layer. When the electrode of the chuck is electrically biased with respect to the substrate by a voltage, an attractive
20 electrostatic force is generated that holds the substrate to the chuck. In monopolar electrode chucks, an electrically charged plasma above the substrate induces electrostatic charge in the substrate that electrostatically holds the substrate to the chuck. A bipolar electrode chuck comprises bipolar electrodes that are electrically biased relative to one another to provide the electrostatic attractive force.

25 With reference to Figures 1a and 1b, the electrostatic attractive force generated by electrostatic chucks **10a**, **10b** can be of different types. As schematically illustrated in Figure 1a, a dielectric layer **11** with a high electrical resistance results in the generation of coulombic electrostatic forces from the

accumulation of electrostatic charge in the substrate 12 and in the electrode 13 of the chuck 10a. The coulombic electrostatic force is described by the equation:

$$F = \frac{1}{2} \epsilon_0 \epsilon_r \left(\frac{V}{t} \right)^2$$

5 where ϵ_0 and ϵ_r are the dielectric constant of vacuum and relative dielectric constant of the dielectric layer 11, respectively, V is the voltage applied to the electrode 13, and t is the thickness of the dielectric layer. The electrostatic force increases with increased relative dielectric constant ϵ_r of the dielectric layer 11.

10 With reference to Figure 1b, Johnsen-Rahbek electrostatic attraction forces occur when an interface 14 of a low resistance dielectric layer 15 and the substrate 12 comprises an interfacial contact resistance much greater than the resistance of the dielectric layer 15, i.e., when the resistance of the dielectric layer 15 from about 10^{11} to about $10^{14} \Omega \text{ cm}$. In these chucks, free electrostatic charge drifts
15 through the dielectric layer 15 under the influence of the electric field and accumulates at the interface of the dielectric layer 15 and the substrate 12, as schematically illustrated in Figure 1b. The charge accumulated at the interface generates a potential drop represented by the equation:

$$F = \frac{1}{2} \epsilon_0 \left(\frac{V}{\delta} \right)^2$$

20 where δ denotes the contact resistance of the air gap 14 between the substrate 12 and the low resistance dielectric layer 15. The Johnsen-Rahbek electrostatic attractive force is much larger for an applied voltage than that provided by coulombic forces because (i) polarization in the dielectric layer 15, and (ii) free charges at the
25 interface 14 (which have a small separation distance from the accumulated charges in the substrate) combine to enhance electrostatic force. A strong electrostatic force securely clamps the substrate 12 onto the chuck and improves thermal transfer rates. Also, it is desirable to operate the chuck using lower voltages to reduce charge-up damage to active devices on the substrate 12.

30

It is known to use ceramic layers to fabricate the low conductivity Johnsen-Rahbek electrostatic chucks. For example, various formulations of Al_2O_3 doped with low levels of 1-3 wt% TiO_2 to form low resistance ceramic layers are disclosed in Watanabe et al., "Relationship between Electrical Resistivity and

Electrostatic Force of Alumina Electrostatic Chuck," Jpn. J. Appl. Phys., Vol. 32, Part 1, No. 2, 1993; and "Resistivity and Microstructure of Alumina Ceramics Added with TiO_2 Fired in Reducing Atmosphere," J. of the Am. Cer. Soc. of Japan Intl. Edition, Vol. 101, No. 10, pp. 1107-1114 (July 1993). In another example,

- 5 U.S. Patent 4,480,284 discloses a chuck having a ceramic dielectric layer made by flame spraying Al_2O_3 , TiO_2 , or BaTiO_3 over an electrode and impregnating the pores of the ceramic layer with a polymer. Whereas pure Al_2O_3 ceramic has a resistivity on the order of 1×10^{14} ohm cm, the alumina/(1-3 wt% titania) ceramic formulations typically have lower resistivities on the order of 1×10^{11} to 1×10^{13} , and
- 10 consequently are more suitable for fabricating Johnsen-Rahbek electrostatic chucks. However, one problem with such ceramic layers is that the volume resistivity of the ceramic decreases to low values with increasing temperature, which results in large current leakages that exceed the capacity of the chuck power supply.

- 15 Another problem with low resistance ceramic formulations is their low charge accumulation and dissipation response time, i.e., the speed at which electrostatic charge accumulates or dissipates in the chuck. The charge accumulation time is the time to reach electrostatic charge saturation and depends on the resistivity of the dielectric layer. Typical resistivities of conventional ceramics of greater than
- 20 $1 \times 10^{12} \Omega \text{ cm}$ result in relatively slow charging times, often as high as 5 to 10 seconds. The high resistance also results in a slow dechucking time, which is the time it takes for the electrostatic charge accumulated in the chuck to dissipate after the voltage applied to the electrode is turned off. It is desirable for the chuck to provide rapid chucking and dechucking to provide high process throughput.

25

- Yet another problem with conventional electrostatic chucks occurs during their use in semiconductor processes that use plasma environments and, in particular, high density plasma environments. A plasma is an electrically conductive gaseous medium formed by inductively or capacitively coupling RF energy into the
- 30 process chamber. High density plasmas which are generated using a combined inductive and capacitive coupling source typically comprise a thin plasma sheath having a large number per unit volume of energetic plasma ions. The high density plasma species permeate into the interfacial gap between the substrate and the chuck, or the potential differences at the backside of the substrate cause formation of

glow discharges and electrical arcing at the backside of the substrate. It is desirable to have an interfacial region that is more resistant to plasma permeation and that can reduce plasma formation even when charged plasma species penetrate into the gap.

5 The formation of glow discharges and arcing at the interfacial gap below the substrate causes additional problems when the substrate is cooled or heated by a heat transfer gas, such as helium, supplied to the interface between the chuck and the substrate via channels in the body of the chuck. The heat transfer gas serves to enhance thermal heat transfer rates. However, the pressure of the heat transfer gas
10 below the substrate counteracts and reduces the electrostatic clamping force exerted on the substrate. Because the semiconductor plasma processing is typically carried out at low pressures, the helium gas pressure increases the size of the interfacial gap below the substrate, causing increased permeation and penetration of the high density plasma into the gap. Additional problems occur when the heat transfer gas passes
15 through gas holes in the chuck that are surrounded by the electrode of the chuck which is supplied by a high power AC voltage. Instantaneous changes in potentials can ionize the heat transfer gas adjacent to the gas distribution holes, particularly when the diameter of the gas hole is relatively large and provides a long mean free path which allows avalanche breakdown of gas molecules in the gas holes. Ceramic
20 chucks typically have large diameter gas holes because it is difficult to drill small holes having diameters less than 0.5 mm because the ceramic at the edges of the holes shatters or chips off during drilling. Arcing and glow discharges within these large diameter gas holes in ceramic chucks cause deterioration of the regions adjacent to the gas distribution holes, including the adjacent dielectric layer and overlying
25 substrate.

Thus, there is a need for an electrostatic chuck that reduces plasma glow discharges and arcing in the interfacial gap between a substrate and chuck, particularly when heat transfer gas is provided to the interface. There is also a need
30 for an electrostatic chuck that deactivates or prevents plasma formation at the gas feeding apertures in the chuck. There is a further need for a chuck having a low conductivity dielectric covering or enclosing the electrode which provides higher electrostatic clamping forces, rapid chucking and dechucking response times, and controlled leakage of current from the electrode.

SUMMARY

The present invention is directed to electrostatic chuck useful for holding a substrate in a plasma environment that provides heat transfer gas at the interface of the substrate and chuck and reduces plasma glow discharges and arcing in the gap between the substrate and chuck. The electrostatic chuck comprises a dielectric member on an electrode, the dielectric member having a top surface for supporting the substrate and at least one gas flow conduit extending through the electrode and dielectric member. The conduit comprises an inlet for receiving gas from a gas supply, an outlet having non-vertical surfaces for delivering the gas to the top surface of the dielectric member, and a dimension sufficiently small to preclude plasma formation therein. An electrical isolator in the outlet of the gas flow conduit electrically isolates the outlet of the conduit from the electrode substantially without blocking the passage of gas through the conduit. The electrical isolator comprises (i) a plasma deactivating dielectric coating on sidewalls of the gas flow conduit, (ii) a preformed insert sized to fit in the gas flow conduit, or (iii) a porous plug substantially filling the outlet of the gas flow conduit, the plug having at least one continuous passageway that allows gas to flow through the plug. In a preferred embodiment the continuous passageway comprises a plasma-deactivating surface area of at least about 20 cm²/gm. Alternatively, the electrical isolator can comprise a tubular insert having a gas flow passageway with a diameter sufficiently small to substantially preclude plasma formation in the passageway.

In a preferred method of forming the electrostatic chuck, a metal plate electrode is formed having an upper surface, and at least one heat transfer gas flow conduit extending therethrough. An electrical isolator is formed in an outlet of the conduit, to electrically isolate gas passing through the outlet of the conduit from the plasma, substantially without blocking the passage of gas through the conduit. The electrical isolator is formed by (i) coating a dielectric material on sidewalls of the gas flow conduit, (ii) positioning a preformed insert in the gas flow conduit, the insert having at least one continuous passageway that allows gas to flow therethrough, or (iii) forming a porous plug of dielectric material in the gas flow conduit. Covering the upper surface of the electrode with a unitary dielectric member selected to expose the passageway in the electrical isolator. Alternatively, the dielectric member can be

formed by mounting a chuck in facing relationship to arcing electrodes. Flowing an inert gas stream through an electrical arc formed between the arcing electrodes to absorb heat from the electrical arc. Spraying a ceramic powder into the hot inert gas stream so that the ceramic powder melts in the electrical arc and energetically

- 5 impinges on the chuck to form a dense, low resistivity, semiconducting dielectric layer adhered to an electrode of the chuck, the semiconducting dielectric layer having by an electrical resistance of from about 5×10^9 to about $8 \times 10^{10} \Omega \text{ cm}$.

In another aspect, the present invention is to an electrostatic chuck
10 having a semiconducting dielectric layer that provides increased electrostatic clamping force, rapid charging, and a fast charge dissipation time. The chuck comprises an electrode that is electrically biased relative to a substrate by a voltage applied to the electrode. A semiconducting dielectric layer covering at least a portion of the electrode, comprises a resistivity in a range $\Delta\rho$. The lower limit of the range $\Delta\rho$ is
15 defined by a first lower resistivity ρ_L that is sufficiently low (i) to allow a leakage current to flow from the electrode when a voltage is applied to the electrode to form accumulated electrostatic charge in the semiconducting dielectric layer, and (ii) to allow the accumulated electrostatic charge to dissipate in less than about one second when the voltage to the electrode is terminated. The upper limit of the range $\Delta\rho$ is
20 defined by a second higher resistivity ρ_H that is sufficiently high to maintain accumulated electrostatic charge in the dielectric layer during operation of the chuck without use of excessively high voltages that damage the substrate. Preferably, the semiconducting dielectric layer has a resistivity of from about 5×10^9 to about $8 \times 10^{10} \Omega \text{ cm}$.

25

In yet another aspect, the present invention comprises an electrostatic chuck having a composite dielectric material covering an electrode of the chuck. The composite dielectric comprises (i) a first dielectric material covering a central portion of the electrode; and (ii) a second dielectric material covering a peripheral portion of
30 the electrode, the second dielectric material comprising an annular rim extending around the first dielectric material. In a preferred version, the composite dielectric layer comprises a semiconducting dielectric covering the central portion of the electrode, the semiconducting dielectric having a resistivity sufficiently low to allow rapid accumulation and dissipation of electrostatic charge therethrough; and an

insulator dielectric covering the peripheral portion of the electrode, the insulator dielectric having a resistivity sufficiently high to substantially preclude plasma discharge therethrough.

5

DRAWINGS

These features, aspects, and advantages of the present invention will become better understood with regard to the following description, appended claims, and accompanying drawings which illustrate versions of the invention, where:

10

Figure 1a (Prior Art) is a schematic view of an electrostatic chuck that operates by coulombic electrostatic forces;

15

Figure 1b (Prior Art) is a schematic view of an electrostatic chuck that operates by Johnsen-Rahbek electrostatic forces;

Figure 2 is a schematic side view of a process chamber comprising an embodiment of the electrostatic chuck of the present invention;

20

Figure 3a is a schematic side view of an electrostatic chuck comprising a unitary body of dielectric material enclosing an electrode and having gas flow conduits extending therethrough;

25

Figure 3b is a schematic top view of the chuck of Figure 3a showing the outlet of the conduits;

Figure 4a is a schematic top view of an electrostatic chuck comprising gas flow conduits in grooves on the surface of the chuck;

30

Figure 4b is a schematic sectional side view of another version of the electrostatic chuck showing the dielectric member with gas flow conduits and electrical isolators;

Figure 5a is a perspective partial sectional view of an annular ring which can be used to form the gas flow channel and gas flow conduits in the chuck;

Figure 5b is a sectional side schematic view showing an electrical
5 isolator comprising dielectric coatings on a gas flow conduit in the annular ring of Figure 5a;

Figure 5c is a sectional side schematic view showing an electrical
isolator comprising a dielectric insert in a gas flow conduit in the annular ring of Figure
10 5a;

Figure 5d is a sectional side schematic view showing an electrical
isolator comprising a porous plug of dielectric material in a gas flow conduit in the
annular ring of Figure 5a;

15
Figures 6 and 7 are schematic side views showing fabrication of
electrical isolators that comprise dielectric inserts fitted in the gas flow conduits;

Figure 8a is a schematic side view showing a dielectric insert having
20 multiple openings in a gas flow conduit;

Figure 8b is a schematic side view showing a dielectric insert made of a
porous material in a gas flow conduit;

25
Figure 8c illustrates three hole patterns that can be used in the dielectric
inserts of Figures 8a and 8b;

Figure 8d is a schematic side view of a composite dielectric insert
comprising a non-porous dielectric sleeve surrounding a porous dielectric center;

30
Figure 8e is a top view of the composite dielectric insert of Figure 8d;

Figure 8f is a schematic side view of a porous dielectric insert positioned
in a gas flow conduit;

Figure 9a is a schematic side view of a composite electrical isolator comprising a non-porous dielectric sleeve surrounding a porous dielectric center, with an annular gas flow opening therebetween;

5 Figure 9b is a schematic side view of a composite electrical isolator comprising a ceramic core and a polymer sleeve;

Figure 9c is a schematic side view of a composite electrical isolator comprising a tubular insert and an outwardly extending spacer ledge;

10

Figure 10a is a schematic side view of a composite electrical isolator comprising a tapered non-porous dielectric sleeve surrounding a porous dielectric center;

15 Figure 10b is a schematic side view of another version of a composite electric isolator;

Figure 11 is a schematic side view of an electrical isolator comprising an embedded electrical lead;

20

Figures 12a through 12f illustrate a method of forming an electrical isolator in a gas flow conduit;

25 Figures 13a through 13c are schematic sectional side views showing fabrication of an electrical isolator comprising a tapered porous plug in a gas flow conduit;

Figure 13d is a partial sectional perspective view of an electrostatic chuck fabricated according to Figures 13a through 13c;

30

Figure 14 is a schematic side view of an electrical isolator comprising porous material covered by dielectric;

Figure 15 is a schematic side view of the electrostatic chuck comprising a composite dielectric layer having a first dielectric layer (such as a semiconducting dielectric) covering a central portion of the electrode, and a second dielectric layer (such as an insulator or dielectric) covering a peripheral portion of the electrode;

5

Figure 16 is a schematic view of a plasma glow discharge spraying apparatus;

Figure 17 is a schematic view of a detonation gun flame spray

10 apparatus;

Figure 18 is a schematic view of an electrode arc spraying apparatus;

and

15

Figure 19 is a schematic sectional view of a preferred grain structure of a semiconducting dielectric layer formed on an electrode using the apparatus of Figure 18.

DESCRIPTION

20

The present invention relates to an electrostatic chuck that exhibits reduced plasma glow discharges and electrical arcing at the interface of the substrate and chuck and provides fast chucking and dechucking response times. The electrostatic chuck is described in the context of holding substrates in a process chamber, as illustrated in Figure 2. The process chamber **50** schematically represents an "HDP" decoupled plasma chamber commercially available from Applied Materials Inc., Santa Clara, California, and described in commonly assigned patent application serial no. 07/941,507, filed on September 8, 1992, which is incorporated herein by reference. The particular embodiment of the process chamber **50** is suitable for

25 plasma processing of semiconductor substrates **55**; however, the present invention can also be used with other process chambers or in other processes without deviating from the scope of the invention.

30

The process chamber **50** includes a process gas source **60** that feeds a gas distributor **62** for introducing process gas into the chamber **50** and a throttled exhaust **65** for exhausting gaseous byproducts. A plasma is formed from the process gas using a plasma generator that couples RF energy into the chamber, such as an inductor coil **70** adjacent to the process chamber **50** powered by a coil power supply **75**. The chamber also includes cathode and anode electrodes **80, 85** that capacitively couple energy into the chamber **50**. The frequency of the RF voltage applied to the cathode and anode **80, 85** and/or the inductor coil **70** is typically from about 50 KHz to about 60 MHz, and more typically about 13.56 MHz; and the power level of the RF voltage/current applied to the coil or process electrodes is typically from about 100 to about 5000 Watts.

An electrostatic chuck **100** is used to hold a substrate **55** for plasma processing in the process chamber **50**. In one version, the electrostatic chuck **100** comprises an electrode **110** covered by, and more preferably embedded in, a dielectric member **115** that electrically isolates the electrode from the substrate. The electrode **110** embedded in the dielectric member **115** provides increased electrical isolation from the plasma environment. Optionally, a base **105** supports the chuck, and a heat transfer fluid circulator **88** circulates heat transfer fluid through the channels **90** in the base to transfer heat to or from the chuck **100**. In another version, shown for example in Figure 3a, the chuck **100** is formed by a dielectric member **115** comprising a layer of dielectric material covering a metal plate that serves as the electrode **110**. By "dielectric member" **115** it is meant both the dielectric layer covering the electrode **110** and the unitary dielectric member having the electrode **110** embedded therein.

25

Referring to Figure 2, to operate the chuck **100**, the process chamber **50** is evacuated to a low pressure, and a robot arm (not shown) transports a substrate **55** from a load-lock transfer chamber through a slit valve into the chamber **50**. A lift finger assembly (not shown) has lift fingers that are elevated through the chuck **100** by a pneumatic lift mechanism. The robot arm places the substrate **55** on the tips of the lift fingers, and the pneumatic lift mechanism, under the control of a computer system, lowers the substrate onto the chuck **100**. After the substrate is placed on the chuck **100**, the electrode **110** of the chuck is electrically biased with respect to the substrate **55** by a chuck voltage supply **120** to electrostatically hold the substrate.

After process completion, the pneumatic lift mechanism raises the lift pins to raise the substrate **55** off the chuck **100**, allowing the substrate to be removed by the robotic arm. Before raising the lift pins, the substrate **55** can be electrically decoupled or dechucked by dissipating the residual electrical charges holding the substrate to the
5 chuck (after the voltage to the electrode is turned off) by grounding the electrode **110** and/or substrate **55**.

In the embodiment shown in Figures 3a and 3b, the chuck comprises a monopolar electrode **110** embedded in, or covered by, the dielectric member **115**.
10 The electrode **110** comprises a metal layer composed of copper, nickel, chromium, aluminum, molybdenum, or combinations thereof; that typically has a thickness of from about 1 μm to about 100 μm , and more typically from 1 μm to 50 μm . For a substrate **55** having a diameter of 200 to 300 mm (6 to 8 inches), the electrode **110** typically comprises an area of about 50 to about 250 sq. cm. In operation, a voltage
15 applied to the monopolar electrode **110** causes electrostatic charge to accumulate in the electrode (or in the dielectric member **115** covering the electrode **110** for Johnsen-Rahbek chucks). The plasma in the chamber **50** provides electrically charged species of opposing polarity which accumulate in the substrate **55**. The accumulated opposing electrostatic charges result in an attractive electrostatic force that
20 electrostatically holds the substrate **55** to the chuck **100**.

Alternatively, the embedded electrode **110** can also comprise bipolar electrodes **110a**, **110b**, as shown in Figure 4a and 4b, that comprises at least two substantially coplanar electrodes that generate substantially equivalent electrostatic
25 clamping forces. A differential electrical voltage is applied to each of the bipolar electrodes **110a**, **110b** to maintain the electrodes at differential electric potential to induce electrostatic charge in the substrate **55** and electrodes. The bipolar electrodes **110a**, **110b** can comprise two opposing semicircular electrodes **110a**, **110b** with an electrical isolation void therebetween that is covered by the dielectric member **115** as
30 shown in Figure 4a. Alternative electrode configurations **110a**, **110b** include inner and outer rings of electrodes, polyhedra patterned electrodes, or other segmented electrode forms embedded in the dielectric member as shown in Figure 4b.

In the arrangement shown in Figure 3b, the electrode comprises an electrically conductive plate **110** that is covered by a dielectric member **115** comprising a layer or coating of dielectric material. The metal plate electrode **110** is shaped and sized to correspond to the shape and size of the substrate **55** to maximize heat transfer and provide a large electrostatic holding surface for the chuck. For example, if the substrate **55** is disk shaped, a right cylindrically shaped plate is preferred. Typically, the metal plate comprises an aluminum cylinder having a diameter of about 100 mm to 225 mm, and a thickness of about 1.5 cm to 2 cm. By "electrode" **110** it is meant any of the aforementioned versions of the electrode, including both the embedded electrode layer and the metal plate electrode.

Particular aspects of the electrostatic chuck **100** of the present invention and illustrative methods of fabricating the chuck will now be described. However, the present invention should not be limited to the illustrative examples and methods of fabrication described herein. Also, it should be understood that each of the individual components, layers, and structures described herein, for example, a semiconducting dielectric layer or electrical isolator structures, can be used independently of one another and for applications other than electrostatic chucking, as would be apparent to those of ordinary skill.

Electrical Isolator in Conduit

One feature of the electrostatic chuck **100** of the present invention relates to a plurality of heat transfer gas flow conduits **150** that extend through one or more of the base **105**, electrode **110**, and dielectric member **115**, as shown in Figures 2 through 4b. A gas supply channel **155** supplies heat transfer gas to the conduits **150** via a gas supply tube **160** connected to a heat transfer gas source **165**. A typical gas flow conduit **150** comprises (1) an inlet **202** for receiving gas from a gas channel **155**, and (2) an outlet **204** for delivering the gas to a top surface **170** of the dielectric member **115** on the chuck **100**. The gas at the top surface **170** of the chuck **100** regulates the temperature of the substrate **55** by transferring heat to or from the substrate **55**. The substrate **55** held on the chuck **100** covers and seals the edges of the dielectric member **115** to reduce leakage of heat transfer gas from the peripheral edge of the chuck **100**. The dielectric member **115** can also comprise

grooves **162** that are sized and distributed to hold heat transfer gas such that substantially the entire surface of the substrate **55** is uniformly heated or cooled, such for example a pattern of intersecting channels that cut through the dielectric member **115**. Preferably, at least one conduit **150** terminates in a groove **162**, and more
5 preferably, the conduits **150** terminate at one or more intersections of the grooves **162**. Alternative groove patterns are described in, for example, U.S. Patent Application Serial No. 08/189,562, entitled "Electrostatic Chuck" by Shamouilian, et al., filed on January 31, 1994, which is incorporated herein by reference. The gas flow conduits **150**, gas supply channel **155**, and grooves **162** are formed by
10 conventional techniques, such as drilling, boring, or milling. Typically, the heat transfer gas comprises helium or argon at a pressure of about 5 to about 30 Torr.

Referring to Figures 3a and 4b, electrical isolators **200** are located in the outlet **204** of the gas flow conduits **150** to reduce or prevent plasma formation from
15 the gas provided by the conduits **150**. This version of the electrostatic chuck is useful for holding substrates in high density plasma environments, for example, where the electromagnetic energy coupled to the chamber is on the order of 5 to 25 watts per cm² at frequencies of 1 to 20 MHZ. High density plasmas typically contain a higher ion density of charged plasma species in thin plasma sheaths and/or plasma
20 ions having ion energies in excess of 1,000 eV. During operation of the chuck **100**, the pressure of heat transfer gas below the substrate **55** counteracts and reduces the electrostatic clamping force on the substrate **55** to form spaces or gaps at the interface. In high density plasma environments, the thin plasma sheath formed above the substrate **55** penetrates into these spaces forming an arc or glow discharge at the
25 back of the substrate **55** which can burn holes in the substrate **55** or chuck **100**. The electrical isolator structures **200** reduce or altogether prevent formation of a plasma in the spaces adjacent to the conduit **150** to significantly improve the lifetime of the chuck **100**.

30 The electrical isolators **200** are fabricated from any dielectric material, including ceramics and thermoplastic or thermoset polymers. Suitable polymers include polyimide, polyketone, polyetherketone, polysulfone, polycarbonate, polystyrene, nylon, polyvinylchloride, polypropylene, polyethersulfone, polyethylene terephthalate, fluoroethylene propylene copolymers, and silicone. Engineering

thermoplastics and thermoset resins loaded with about 35% to about 45% by volume glass or mineral fillers can be injection molded to form the electrical isolator **200**.

Suitable ceramic materials include Al_2O_3 , AlN , SiO_2 , Si_3N_4 ; of which aluminum oxide, aluminum nitride, silicon nitride, and mixtures thereof, are preferred. More preferably,

5 the dielectric material comprises aluminum oxides which provides a degree of chemically compatibility with the aluminum of the electrode and base or a mixture of aluminum oxides and silicon oxides, as described below. The dielectric breakdown strength of the dielectric material is preferably from about 4 to 40 volts/micron, and the electrical resistance is preferably from about 10^{11} to 10^{20} Ω cm.

10

Preferably, the electrical isolator **200** comprises a plasma-deactivating material that is capable of deactivating, and consequently altogether preventing formation of a plasma adjacent to the gas conduits **150** below the substrate **55**. The plasma-deactivating material comprises a porous, high surface area material lining the

15 internal surfaces of the conduit **150** that prevents plasma formation by limiting the kinetic energy and/or dissipating the electrical charge of ionized gaseous species. Although the plasma deactivation mechanism is not precisely known, it is believed that the high surface area provides active recombination sites that strip the electrical charge from plasma species incident on the surface. Also, tortuous small diameter

20 pores in the plasma deactivating material control the kinetic energy of charged plasma species in the pores by providing a small mean free path that limits acceleration, and resultant avalanche breakdown of the charged species, that is necessary to ignite a plasma. The small mean free path also results in fewer energy transferring collisions between charged gas species which further reduces plasma formation. In this

25 manner, the porous and/or high surface area plasma-deactivating material prevents formation of a plasma in the regions below the substrate that are adjacent to the conduits **150**.

The electrical isolators **200** preferably comprise continuous passages

30 therethrough that have small linear dimensions (i.e., diameter or length) which prevent avalanche breakdown and plasma formation in the holes. Preferably, the diameter of the conduits is less than about 0.5 mm, and more preferably less than about 0.25 mm. At these dimensions, the operating pressure and power of the chamber **50** are too low to permit ionization of the heat transfer gas, thereby preventing formation

of a plasma in the regions adjacent to the outlets of the gas flow conduits **50** and electrically isolating the surrounding electrode **110**. The shape and distribution of the pores, volume percent porosity, pore size and distribution, and surface area of the plasma deactivating material all affect its plasma deactivating properties. Preferably, the plasma deactivating material comprises small diameter, randomly oriented, tortuous pores which, in conjunction with the spaces between the separated grains, form continuous pathways or pore passageways having small diameters extending through the material. The randomly orientated pores are desirable to produce tortuous passageways that avoid straight line pathways while providing continuous passageways that allow heat transfer gas to flow therethrough. The diameters of these pathways are typically of the same order of magnitude as the ceramic particles used to form the porous material. The tortuous pathways increase the number of effective collisions between the charged gaseous species and between the charged species and the pore wall surfaces. Preferably, the porous material comprises pore passageways that are typically sized from about 250 to about 375 μm in length, and having diameters ranging from about 1 to about 100 μm . Preferably, the volume percent porosity of the plasma deactivating material is from about 10 to about 60 volume %, and more preferably from about 30 to about 40 volume %. Most preferably, the plasma-deactivating material typically comprises a surface area from about 20 cm^2/g to about 300 cm^2/g .

The plasma-deactivating material can be formed in the conduit **150** using conventional ceramic fabrication, thermal spraying. In one preferred embodiment, the plasma-deactivating material comprises a mixture of aluminum oxides and silicon oxides. The aluminum oxide grains are held together with intermixed silicon oxide glassy phase, and the resultant structure comprises continuous pathways that are formed between the ceramic grains and through its pores. The porous material can be formed by mixing the desired composition of alumina and silica, pouring the formulation in a mold shaped as the insert, and sintering the mixture at 1400°C to melt the silica glass around the alumina. The resultant structure has a high porosity of about 5 to 50%, and tortuous pores having diameters typically ranging from 1 to about 25 microns.

In another method of fabrication, a flame spraying method is used to form the plasma-deactivating material. In this method, a high temperature flame of a combustible mixture of gases, for example, acetylene and oxygen, is formed and a ceramic powder formulation corresponding to the desired composition of the plasma
5 deactivating material is sprayed through the hot flame. The flame spraying method provides a relatively low heat or kinetic energy input to the sprayed ceramic particles, allowing them to move relatively slowly and cool off during travel to the incident surface. The cooling and low kinetic energy impact on the conduit walls results in solidified plasma-deactivating material that comprises spherical ceramic particles which
10 retain their shape and have extensive tortuous pathways between the particles and have high surface areas.

Electrical Isolator Structures

15 The electrical isolator **200** in the gas flow conduit **150** can have many different shapes and forms. In one embodiment that is easy to fabricate, the gas supply channel **155** with gas flow conduits **150** is machined in an annular metal ring **180** that is inserted in, and forms a portion of the electrode **110**, as illustrated in Figures 5a to 5d. Referring to Figure 5a, the annular ring **180** comprises a gas supply
20 channel **155** machined in its underside in close proximity to its upper surface with a thin metal layer **185** therebetween. Conduits **150** are machined through the metal layer **185** in an annular configuration. The inlets **202** of the conduits **150** are bored through the thin layer of metal **185** prior to the application of the overlying dielectric member **115** (not shown), or the conduits can be formed after the application of
25 dielectric member by simultaneously boring outlet holes **204** through the dielectric member **115** and thin metallic layer **185**. The annular ring **180** is sized to fit along the periphery of the electrostatic chuck **100**, and is sealed at edges and surfaces **190** adjacent to the central portion of the electrode **110** to reduce leakage of heat transfer gas. Preferably, as shown in Figure 5b, the annular ring **180** and electrode **110** form
30 a first annular gas flow channel **155a** and an overlying and concentric second annular channel **155b** having a larger width. The annular ring **180**, including a plurality of predrilled conduits **150** spaced apart around the length of the annular ring, is fitted into this combination of channels. The dielectric member **115** (not shown) is applied over the surface of the ring **180** and processed to the desired thickness. Thereafter,

an opening is drilled through the dielectric member **115** to connect to the conduit **150** to allow heat transfer gas to flow from channel **155** to the surface of the electrostatic chuck.

5 In the version shown in Figure 5b, the electrical isolator **200a** in the gas flow conduit **150** comprises a plurality of dielectric coatings **205**, **210** covering the sidewalls of the conduit. The dielectric coatings **205**, **210** can be deposited directly on sidewalls of the conduits formed in an annular ring **180** (as shown) or can be deposited on top of another "sidewall" dielectric coating that is initially deposited on
10 the sidewalls of the conduit **150**. For example, the first or inner sidewall dielectric coating **210** can comprise a highly electrically insulative layer, and the outer coating **205** can comprise a coating of porous plasma deactivating material.

Figure 5c illustrates another embodiment in which the electrical isolator
15 comprises a preformed dielectric insert **200b** inserted in the conduit **150** and having at least one continuous hole or passageway **206** that allows heat transfer or other gas to flow through the conduit **150**. The dimensions of the hole are selected to reduce plasma formation, and preferably comprise a diameter equal to or less than about 0.4 mm. The preformed dielectric insert **200b** can be fabricated from electrical
20 insulator or dielectric material, plasma-deactivating material, or mixtures thereof. In general, the dielectric inserts **200b** are fabricated by positioning the insert into the conduit **150** drilled in an annular ring **180** with an apex of the insert extending from the electrode **110**. A layer of dielectric (not shown) is formed over the surface **208** of the annular ring **180** and electrode **110** and processed to the desired thickness to
25 expose the hole **206** of the insert **200b**. Thereafter, the apex is removed, for example, by grinding or ablating; or a dielectric member **115** is formed around the apex to hold the dielectric insert **200b** in position. Dielectric insert **200b** electrical isolates the annular ring **180** from process plasma which may penetrate the outlet of gas flow conduit **150** and reduces arcing between the substrate **55** supported upon
30 the surface of the electrostatic chuck **100** and the electrically conductive annular ring **180**.

Figure 5d illustrates yet another embodiment of the present invention where the electrical isolator comprises a plug **200c** of dielectric material that

substantially fills up the outlet of the gas flow conduit **150**. The plug **200c** comprises continuous pathways such as interconnected pore passageways, microcracks, and separated grain boundary regions that extend through the entire plug. Suitable plugs **200c** have porosities ranging from about 10 to about 60 volume%. In this

5 embodiment, an overlying dielectric member **115** covers the plug **200c** to hold the plug in place, and an opening is drilled through the dielectric member and stopped on the top surface of the porous plug **200c**. The continuous pore pathways formed by the intersection of one or more pores, microcracks, and separated grain boundary regions in the porous plug **200c** allow heat transfer gas to flow therethrough, while

10 reducing or preventing limiting plasma formation in the conduit **150**.

Another version of the electrical isolator, as shown in Figure 6, comprises a cylindrical dielectric insert **300** having a boss **301** around its circumference and a vertically extending cavity **308** extending from the bottom and

15 having a closed off apex **306**. The dielectric insert **300** is conically shaped with tapering sides **314** at an angle of about 26° . The central portion is cylindrical with a diameter of about 1.5 mm (60 mils), and the entire insert has a diameter of about 3.2 mm (127 mils). A socket hole **313** is bored in the electrode **110** to connect to the underlying gas supply channel **155** in the electrode **110**. Dielectric insert **300** is

20 fitted into the socket hole **313** with the bottom of its boss **301** resting on the side portions of socket hole **313**, leaving a clearance between the bottom of dielectric insert **300** and the gas supply channel **155**. Heat transfer gas flows from the gas supply channel **155** into the vertically extending cavity **308** formed within dielectric insert **300**. After the dielectric insert **300** is fit into socket hole **313** of electrode **110**,

25 a dielectric member **302** is formed over the surfaces of both the dielectric insert **300** and electrode **110**. Thereafter, the dielectric member **302** is ground back to line **304** which is below the closed end of the cavity **308** of the insert **300**, to expose the cavity **308** at its apex **306** allowing heat transfer gas to flow therethrough.

Preferably, a plurality of dielectric inserts **300** are inserted into respective socket holes

30 **313** spaced apart along the electrode **110**, or into socket holes formed in the annular ring **180** which is thereafter joined to the electrode **110**.

Figure 7 shows another embodiment of the electrical isolator comprising a tubular sleeve **320** shaped as a right circular cylinder with an axial opening **328**

therethrough. The axial opening **328** passes through the entire sleeve **320** (or has an upper closed end, not shown). The tubular sleeve **320** is inserted in corresponding socket holes **334** in the electrode **110** that connects to the underlying gas supply channel **155** of the chuck **100**. A second socket hole **335** is drilled partially through
5 electrode **110** to form an annular ledge **336** at the bottom of the socket hole **335** that supports the tubular sleeve **320**. Optionally, a tubular sleeve **320** is held in the electrode **110** by an annular weld or brazed joint **326** extending around the sleeve **320** at the top of the electrode **110** or by an interference fit. After the tubular sleeve **320** is fitted into socket hole **335**, a dielectric member **322** is formed over the surface
10 of insert sleeve **320**, and thereafter ground back to line **324** to expose the opening **332** of the sleeve **320**. Instead of welding sleeve **320** in place, layer **322** can be processed so that it leaves dielectric insert **320** unexposed. Openings **332** are then drilled through semiconducting dielectric member **322** to connect with opening **328** in dielectric insert sleeve **320**. Preferably, a plurality of such tubular sleeves **320** are
15 positioned around the electrode **110**.

Figures 8a to 8f show additional embodiments of the electrical isolators **200** of the present invention. The overlying dielectric member **115** which forms the upper surface of the electrostatic chuck **100** is not shown so that the underlying
20 structures can be shown with more clarity. The dielectric insert **510** illustrated in Figure 8a comprises a plurality of openings **516** leading to gas flow channel **155**. Dielectric insert **510** is shaped to fit into annular ring **180** and comprises a dome-shaped upper surface that, after application of an overlying dielectric member (not shown), can be ground or ablated to expose the openings **516** of the dielectric insert
25 **510** while leaving a portion of the upper surface of the electrode **110** and the insert covered by the overlying dielectric member.

The electrical isolator of Figure 8b also comprises a dielectric insert **520** that uses an overlying dielectric layer (not shown) to hold it in place. The overlying
30 dielectric layer (which serves as the dielectric member **115**) is applied over the surface of insert **520**, annular ring **180**, and electrode **110**; and thereafter, ground or ablated to the desired thickness. The conduits through the overlying dielectric layer and dielectric insert **520** are drilled through the overlying dielectric layer and insert **520** to connect to gas flow channel **155**. Figure 8c shows typical hole patterns which can

be drilled through the dielectric inserts **510**, **520** of Figures 8a and 8b, respectively. Alternatively, the dielectric inserts **510**, **520** can be fabricated from porous material without drilling holes therethrough, allowing the continuous pores and passageways of the insert to allow heat transfer gas to flow therethrough.

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In the embodiment shown in Figure 8c, the conduits or grooves are formed in the electrical isolator **200** by laser micro-machining, a grinding wheel, or diamond/cubic boron nitride drilling. A preferred laser is an excimer UV laser having a short wavelength and high energy that is operated at a relatively low power level to
10 reduce redeposition of drilled aluminum particles onto the walls of the openings and onto the dielectric member. Such aluminum contamination can cause arcing of the dielectric member **115**. The number of outlet openings **204** for the conduit depends on the heat transfer load and the gas flow rate required to handle this load. For an electrostatic chuck **100** used with an 200 mm (8 inch) silicon wafer, a suitable
15 number of outlets **204** or openings for the gas flow conduits range from about 12 to about 24, and the openings are positioned in a ring-shaped configuration around the perimeter of the electrostatic chuck **100**. Preferably, the diameters of the outlets **204** are less than or equal to about 0.20 mm, and more preferably about 0.175 mm.

20

Another series of dielectric insert designs, shown in Figures 8d through 8f, are positioned in the annular ring **180** fitted in an electrode **110** having two annular trenches **602**, **604** therein. In Figure 8d, the dielectric insert **610** comprises a tubular non-porous dielectric sleeve **616** surrounding a porous dielectric insert **618**. The dome-shaped upper portion of dielectric insert **610** allows the dielectric member
25 **115** (not shown) to hold it in place. The overlying dielectric member **115** is ground or ablated to expose porous dielectric insert **618**, as shown in the top view of Figure 8e. This allows heat transfer gas to flow through channel **155** and porous dielectric insert **618** to the surface of the dielectric member. The non-porous dielectric sleeve **616** is shaped to form a small angle with the adjacent surface **612** of the annular ring **180**,
30 allowing deposition of a contiguous coating without voids or cavities at the interface of the sleeve **616** and ring **180**. The upper surface of dielectric insert **616** is roughened to provide a strong bond with the dielectric member **115**. Preferably, dielectric sleeve **616** has greater tensile strength and modulus than the insert **618** to provide a more reliable joint between sleeve **616** and annular ring **180**. This also

reduces formation of voids between dielectric sleeve **616** and ring **180** which can cause flaws in the overlying dielectric coating (not shown). Figure 8f illustrates another dielectric insert **620** that entirely comprises a porous dielectric material, such as the plasma-deactivating material having continuous pore passageways therein. The
5 porosity and pore size distribution of the porous material is selected to reduce formation of plasma in and adjacent to the dielectric insert **620**.

Figure 9a shows yet another preferred configuration of a dielectric insert **630** comprising a dielectric sleeve **636** and a dielectric center plug **638**. An annular
10 ring shaped opening **640** is between sleeve **636** and center plug **638**. Center plug **638** is held in place by an adhesive or ceramic bonding material such as fusible glass ceramic **642**, which anchors plug **638** to sleeve **636**. By adjusting the size of dielectric center plug **638**, the gas flow rate through dielectric insert **630** is adjusted. Again, an overlying dielectric member **115** (not shown) is applied over the surfaces of
15 the electrode **110**, annular ring **180**, and dielectric insert **630**. Subsequently the overlying dielectric member **115** is processed to expose the opening **640** in dielectric insert **630** while leaving at least a portion of sleeve **636** entrapped below the overlying dielectric member.

20 Figure 9b shows a preformed electrical isolator **200** comprising a porous plug **820** in a polymer sleeve **832**, the sleeve sized to hold the porous plug **820** in the conduit **150** in the dielectric member **115** or electrode **110**. Preferably, the sleeve **832** is made of a ductile, lubricative, and slippery surfaced polymeric material, such as Teflon® (trademark of DuPont Company), or a silicone containing material. Because of
25 its ductility and lubricative surface, the sleeve **832** facilitates insertion of the hard, brittle, and fracture-prone ceramic porous plug **820** into the conduits **150** of the chuck. Also, the ductile and flexible polymer conforms its shape to fit snugly into the conduit, to eliminate the need for machining the conduit and/or the porous plug to precise tolerances. In the fabrication process, the porous plug **820** is first press fitted
30 into the polymer sleeve **832**, and the assembled electrical isolator **200** is then press fitted into the outlet **204** of the conduit **150**. The preformed insert in the sleeve **832** defines at least one continuous passageway that allows gas to flow through the insert. While the ceramic insert can be fabricated from aluminum oxide, aluminum

nitride, silicon dioxide, zirconium oxide, silicon carbide, silicon nitride, or mixtures thereof; of which aluminum oxide, aluminum nitride, or silicon nitride, are preferred.

In the embodiment shown in Figure 9c, the electrical isolator **200** comprises an outwardly extending spacer **835** that is sized to hold an insert **830** in conduits **840, 850**. Preferably, the spacer **835** is made of a ceramic or plastic material, such as Teflon® (trademark of DuPont Company). The spacer **835** has a top tubular portion **860** and a bottom tubular portion **865** separated by a central ledge **870** having a cross-sectional area greater than the inner diameter of conduits **840, 850**. The spacer **835** aligns and holds in place the tubular insert **830** during assembly of the chuck, and prevents ingress of bonding material **855**, such as molten solder, for example indium, into the conduits **840, 850** during bonding of the chuck **100** to a base **105**. Prior to joining the chuck **100** to the base **105** the top tubular portion **860** is inserted into conduit **840** on the lower surface of the chuck and the bottom tubular portion **865** is then aligned with and inserted into conduit **850** in the base. The base/chuck assembly is placed into a mold, which is then evacuated by a vacuum pump and into which molten solder is injected. The thickness of the central ledge **870** of a plurality of spacers **835** interposed between the chuck **100** and the base **105** hold the chuck at a predetermined distance from the metal base to provides a uniform bond line of predetermined thickness. A uniform bond line provides uniform thermal resistance which in turn promotes good heat transfer between the base **105** and the chuck **100**. This is particularly advantageous in the embodiment in which the base **105** advantageously comprises heat transfer fluid channels **90** that are used to circulate heat transfer fluid to heat or cool the chuck **100** to regulate the temperature of the substrate **55**. As shown in Figure 2, the base **105** comprises channels **90** through which heat transfer fluid can be circulated by fluid circulator **88** to heat or cool the chuck **100** as needed to maintain substrate temperature.

Yet another embodiment of a composite dielectric insert is shown in Figure 10a. In this embodiment, the dielectric insert **650** comprises a porous dielectric material shaped in the form of an inverted T-shape structure, and having a boss **652** around its circumference, the boss comprising a vertical cylinder **654** with a closed upper end **656** centered on a disc portion **658**. The vertical cylinder **654** of the boss **652** typically has a diameter of about 1 to about 3 mm and the disc portion

658 a diameter of about 3 to about 5 mm. A non-porous sleeve **660** is shaped to fit and surround the vertical cylinder **654**. The tapered upper surface of the non-porous sleeve **660** is roughened to allow strong adherence to the overlying dielectric member **115**. To fabricate the chuck, a socket hole **662** is bored in the electrode **110** to
5 connect to the underlying gas supply channel **155** in the electrode **110**. Dielectric insert **650** is fitted into the socket hole **662** with the bottom of its boss **652** resting on the bottom portions of socket hole **662**, exposing the relatively wide area of the disc **658** to allow heat transfer gas to ingress into the insert **650** from the gas supply channel **155**, and thereafter flow into the vertically extending cylinder **654**. After the
10 insert **650** is fit into socket hole **662** of electrode **110**, a dielectric member **115** is formed over the surfaces of the sleeve **650**, the tapered roughened surface of the sleeve **660**, and adjacent surfaces of the electrode **110**. Thereafter, the dielectric member **115** is ground back to exposed the closed end of the cylinder **654**, and the porous pathways therein allow heat transfer gas to flow through.

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In the embodiment shown in Figure 10b, the dielectric insert **670** comprises a boss **672** having conically shaped tapering sides at **674** at an angle of about 26°. In this version, a non-porous sleeve **676** comprising a tubular shape with an inwardly extending cap **678** is shaped and sized to fit over the dielectric insert
20 **670**. The upper surfaces **680** of the nonporous sleeve **676** are roughened to form a surface having a strong mechanical adherence. Glass or ceramic cement can be used to bond the cap **678** of the nonporous insert onto the boss **672** of the porous insert. Thereafter, the composite insert is positioned in a corresponding hole **682** in the electrode **110**, and the dielectric member **115** is formed over the insert and thereafter
25 ablated or ground to expose the surface of the porous insert, as described above.

In the embodiment shown in Figure 11, the electrical isolator **200** comprises a dielectric material shaped in the form of a column or pin **836** having an embedded electrical conductor lead **838** that is electrically connected to the grounded
30 base **105** of the chuck. The lead **838** is electrically connected to the base that is typically maintained at an electrical ground, to bring the ground potential applied to the base closer to the substrate to suppress the formation of plasma and electrical arcing in the conduit **150**. Each gas supply channel **155** of the chuck contains a centrally positioned dielectric pin **836** having a diameter sized smaller than the conduit

to provide an annular or circumferential opening that allows gas to flow from the channel **155** past the dielectric pin **836** and below the substrate. The dielectric pin **836** is held in place in channel **155** by an adhesive or bonding material **720** applied to the base of the pin.

5

Figures 12a through 12f illustrate a preferred embodiment of the present invention which provides ease in fabrication. Referring to Figure 12e, the final structure comprises an electrode **110** including at least one gas supply channel **155** which contains dielectric insert **718**. Dielectric insert **718** is sized to provide an annular opening **716** that allows gas to flow from the channel **155** and past the dielectric insert **718**, as shown in Figure 12f. The dielectric member **115** overlying electrode **110** also includes at least one opening directly over channel **155**, the opening sized to allow insertion of dielectric insert **718** with the annular opening **716** around the insert **718**. Thus, heat transfer gas can flow from channel **155** to the surface of the dielectric member **115** via the annular opening **716**. Dielectric insert **718** is held in place in channel **155** by an adhesive or bonding material **720**. It is not critical that dielectric insert **718** be centered in the opening **710** through the dielectric member **115**, as long as the heat transfer gas can flow through the annular opening **716**.

20

Fabrication of this embodiment, is shown in Figures 12a through 12f. Figure 12a shows a gas supply channel **155** formed in the electrode **110**, and at least one hole or opening **710** is drilled through the surface **706** of the electrode **110** to connect with heat transfer gas flow channel **155**, as shown in Figure 12b. The diameter of opening **710** is generally, but not by way of limitation, about 2 mm (0.080 inches) or larger. Although this diameter is not critical, the tolerance of the selected diameter should be held within about ± 0.13 mm (± 0.005 inches). As shown in Figure 12c, a space-holding masking pin **712** is then held in opening **710** and channel **155** so that overlying dielectric member **115** can be formed without excessive dielectric material entering into opening **710**. This is the reason the tolerance of the diameter of opening **710** should be carefully controlled. Masking pin **712** is preferably constructed from a material which does not adhere to the dielectric member **115**, such as a Teflon® (trademark of DuPont Company) masking pin **712**. Space-holding masking pin **712** is generally 3 to 6 diameters high; being sufficiently

tall to allow pulling out the pin **712** after forming the dielectric member **115**, and sufficiently small to reduce shadowing of the dielectric member **115** around masking pin **712**.

5 The dielectric member **115** is typically applied to a thickness which is from about 250 to about 600 microns (10 to 20 mils) greater than the desired final thickness; and after application of dielectric member **115** and removal of masking pin **712**, as shown in Figure 12d, the dielectric member **115** is ground to final thickness, and cleaned of grinding residue. This provides a smooth, flush surface **722** to the
10 dielectric member **115**, which is flat to at least 25 microns, i.e., all points on the surface lie within two parallel planes spaced 25 microns apart. Annular opening **716** typically has a diameter of about 2 mm (0.08 inches) or more to permit removal of surface residue, such as the grinding residue. This is an advantage over other
15 embodiments of this invention which have smaller diameter openings and are more difficult to clean.

A measured quantity of adhesive or bonding ceramic **720** is then deposited at the base of channel **155**, directly beneath opening **710**. The thickness of
20 adhesive layer **720** is sufficient to compensate in variations in the length of dielectric pin **718** while maintaining the smoothness of the chuck surface across the dielectric member **115** and dielectric pin **718**. Dielectric pins **718** are typically fabricated from ground ceramic, such as alumina, and have a diameter ranging from about 0.76 mm to about 0.102 mm (0.003 to 0.005 inches) less than the bore diameter of opening
25 **710**. Typically, the dielectric pins **718** are cut at least $\frac{1}{4}$ mm (0.010 inch) shorter than the bore depth through dielectric member **115** and electrode **110** to the bottom **726** of channel **155**. Dielectric pins **718** may be cut as much as 1 mm (0.040 inch) undersized in length.

Dielectric pins **718** are inserted through opening **710** and into adhesive
30 **720** resting on the bottom **726** of channel **155**. It is important that the pins **718** are positioned to provide a flush top surface **724**, and this is accomplished using the depth of penetration of pins **718** into the thickness of adhesive **720** to make up any differences in length of pins **718**. It is not critical that dielectric pins **718** be centered within the bore openings **716** and **710**, and variation is allowable, as apparent from

Figure 12f. The heat transfer gas flows out of the annular opening **716** between dielectric pin **718** and electrode **110**. In an alternative method, the dielectric pin is held in place by an opening machined into the bottom surface **726** into which dielectric pin **718** is interference fitted or staked.

5

For electrostatic chucks **100** used to hold 8-inch diameter semiconductor wafers, approximately 12 to 24 conduits having dielectric inserts **718** are positioned in a ring around the periphery of the chuck **100**. The circular opening **710** in electrode **110** (or annular ring **180**) typically ranges from about 1 to about 10 mm (0.040 to about 0.400 inches) in diameter, and the dielectric insert has an outer diameter of approximately 0.123 mm (0.005 inches) smaller than the diameter of the cavity. These dimensions are adjusted depending on the kind of heat transfer gas used, the pressure in the process chamber, and the desired gas flow rate to the surface of the electrostatic chuck **100**.

15

Where the electrical isolator **200** is in close contact with an opening in the electrode **110** or annular ring **180**, a close contact can be achieved using an interference fit or press fit. During press fitting of the dielectric insert **200b** in the opening, a uniform pressure should be applied to the surface of the dielectric insert to prevent fracture of the brittle insert using a tool designed to fit and apply even pressure to the surface of the dielectric insert during press fitting. In general, electrical isolators **200** comprising ceramic dielectric inserts should be small in size, about 0.5 mm (0.020 inches) to about 10 mm (0.400 inches) in diameter, to avoid mechanical failure from compressive loads applied as a result of temperature cycling during substrate processing. The incompatibility of the thermal coefficient of expansion between the ceramic dielectric and the electrode **110** of the electrostatic chuck **100** creates these compressive loads during temperature cycles. The small size of the dielectric insert also makes it possible to compression fit the insert into the electrostatic chuck **100** in an interference fit. Also, the insert should be tapered toward its bottom edge to permit easier insertion into the receiving cavity. Since alumina containing dielectric inserts have relatively hard and sharp edges, the insert can be pressed into the underlying aluminum cavity with sufficient pressure to cut into the aluminum and provide a close press fit. A close press fit is also obtained by deforming the conductive material in contact with the dielectric insert (staking). The

30

dielectric insert can also be closely fitted using a machined interference fit of about at least about 0.025 mm (0.001 inch). Also, a large interference fit between the insert and surrounding base increases the strength of the bond of the overlying dielectric coating applied on the base and insert, reducing thermal expansion microcracking of the overlying dielectric member, which can lead to penetration of high density plasmas, and rapid breakdown of the dielectric member overlying the insert and base.

Another structure suitable for forming the electrical isolator **200** comprises a porous plug **800**, the manufacture of which is shown in Figures 13a to 13d. The porous plug **800** has substantially continuous pores, and/or interconnected microcracks and pores that forms continuous pathways that allow heat transfer gas to flow through the plug **800**, while simultaneously deactivating or limiting plasma formation in the conduit **150**. Referring to Figure 13a, a hole having a straight walled inlet **802** and a tapered outlet **804** is bored through the electrode **110** to form a gas flow conduit **150**. Thereafter, an underlying dielectric layer **806** is deposited on the sidewalls of the conduit **150**, and the surface **810** of the dielectric layer **806** at the outlet **804** is roughened, for example by grit blasting, to form a rough serrated surface that provides strong mechanical adherence of the porous plasma deactivating material, and of the dielectric member **115** overlying the conduit. Preferably, the dielectric layer is deposited by plasma spraying to provide rough surfaces yielding better adhesion. A tapered conically shaped porous plug **800** is formed over the roughed surface to fill the outlet of the conduit **150**, by for example, thermal spraying. Alternatively, as shown in Figure 13d, one or more conduits **150** terminating in circular grooves **805** are formed in the surface of the chuck **100**, a layer of dielectric material **806** is deposited in the groove **805** and roughened, and a porous covering **803** is filled in the groove **805**. Preferably, at least one groove **805** is formed in the peripheral edge of the electrode **110** to cool the peripheral edge of the substrate. This configuration has the further advantage of facilitating manufacture by allowing the underlying dielectric layer **806** and the porous covering **803** to be deposited by rotating the chuck **100** under the applicator nozzle of the spraying apparatus. Preferably, plasma or flame spraying is used to form the porous plug structure **800** to obtain a high porosity plug. Thereafter, the overlying dielectric member **115** is deposited on the plug **800** to hold the plug in place, as shown in Figure 13b. Either an opening is drilled only through the dielectric member **115** (not shown) and stopped

on the top surface of the porous plug **800**; or the surface of the dielectric member is ground or ablated until the apex **812** of the plug is exposed, as shown in Figure 13c, allowing heat transfer gas to flow through the porous pathways in the plug.

5 In the embodiments shown in Figures 13a to 13c, the tapered outlet **804** comprises a nonvertical surface which allows firm adherence and uniform deposition of a thermally sprayed dielectric member **115**. It has been discovered that when a thermally sprayed coating is applied to a perpendicular surface, i.e., in the same plane as the spraying direction of the spraying process, the solidified spray has low
10 adhesion on the vertical surfaces and forms loose grains near the corners and edges of the vertical surfaces resulting in spalling and flaking off of the dielectric member **115**. Thus, preferably, the outlet **804** of the conduit **150** has non-vertical surfaces that define a tapered region therebetween. The tapered region is also configured to reduce the penetration of plasma into the conduits **150**, the sloped non-vertical walls
15 forming an apex at the surface of the chuck. The porous plug **800** is deposited in the tapered region to substantially entirely fill the tapered region of the outlet. Typically, the outlet **804** has tapered sides that form an angle of about 26° with a vertical axis through the conduit, and comprises a first smaller diameter of at least about 1 mm, and a second large diameter of less than about 5 mm.

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 In yet another method of fabrication, the electrical isolators **200** are formed by filling the outlet **204** of the conduit **150** with porous material. The outlet **204** of the conduit **150** forms an annular ring that extends continuously along, and adjacent to, the circumferential perimeter of the chuck, as shown in Figure 13d, to
25 provide heat transfer gas below the entire perimeter of the substrate **55**. Preferably, granules of dielectric material mixed with organic binder are packed in the outlet **204** of the conduit **150**, and sintered to form granular material bonded to the inner surfaces of the conduit **150** having convoluted passageways and interconnected pores. Because the dimensions of the resultant interconnecting pores tend to be
30 roughly equal to the size of the granules, it is also preferred to use ceramic granules having an average mean diameter of less than or equal to about 0.4 mm, and more preferably less than or equal to 0.25 mm. Preferably, the granules consist of the same material as the dielectric member **115** to increase their adhesion to the inner surface of the gas conduits **155** and reduce thermal stresses. Thereafter, a layer of

ceramic material is deposited over the electrical isolator **200**, and a gas flow or gas pressure is maintained in the electrical isolator **200** during deposition of the overlying dielectric layer to prevent plugging of pre-drilled holes or pores of the porous materials. After the dielectric member **115** is formed on the surface of the chuck

5 **100**, a thickness of about 200 to 250 μm of the top surface of the dielectric member is ground or ablated to expose the underlying electrical isolator **200**. The grinding process is performed using a diamond grit-coated grinding wheel that is registered accurately relative to the chuck **100** to grind-off the correct thickness of the dielectric layer, and deionized water grinding fluid is used to reduce contamination.

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Another embodiment of the porous plug configuration **820** is shown in Figure 14. In this version, a hole having a straight walled inlet **822** and a tapered outlet **824** having a continuously varying multi-radius sidewalls, is bored through an annular ring **180** to form the gas flow conduit. The annular ring is mounted in a

15 cavity in the electrode **110** so that the ring **180** rests upon ledges **826** in the base. Thereafter, an underlying dielectric member **828** is deposited on the outlet **824** of the conduit and adjacent surfaces of the electrode **110**. A tapered conically shaped porous plug **800** is formed over an underlying dielectric member **828** to substantially fill the outlet **824** by a suitable deposition method, such as for example thermal

20 spraying, and more preferably by plasma or flame spraying. Thereafter, an overlying dielectric member **115** is deposited on the plug **800** to hold the plug in place. Either an opening is drilled only through the dielectric member **115** (not shown) and stopped on the top surface of the porous plug **820** without drilling through the plug; or the surface of the dielectric member is ground or ablated until the apex of the plug is

25 exposed (not shown) allowing heat transfer gas to flow through the porous pathways in the plug.

Semiconducting Dielectric Member

30

In another aspect, the present invention is directed to an electrostatic chuck **100** comprising one or more electrodes **110** covered by, and more preferably embedded in, a dielectric member having semiconducting properties that provides fast charging and discharging response time and rapid chucking and dechucking of substrates **55** held on the chuck **100**. The semiconducting dielectric member **115** can

be used in conjunction with the electrical isolators **200** or separately without using the electrical isolators **200**. The dielectric member **115** comprises a unitary body of semiconducting dielectric material covering or enclosing the electrode **110** therein, as shown in Figures 2 and 4b; or one or more layers of semiconducting dielectric material
5 covering an electrically conductive electrode **110** that serves as the electrode **110**, as shown in Figure 3a. In both versions, the semiconducting dielectric member **115** comprises a top surface **170** configured to support a substrate. Upon application of a voltage to the electrode **110**, the semiconducting properties of the dielectric member **115** allow rapid accumulation of electrostatic charge in the dielectric member,
10 particularly at the interface between the dielectric member and the substrate **55**. For electrostatic charge to accumulate in the dielectric member **115** the semiconducting material has to be sufficiently leaky to allow a small leakage current to flow from the electrode **110** through the dielectric member **115**. If the leakage current is too small, chucking speed is slow, and substrate processing throughput is reduced. Conversely,
15 an excessively high leakage current can damage the active devices formed on the substrate **55**.

The amperage of the leakage current that can be tolerated in the chuck **100** also depends upon the voltage applied to the electrode **110**. The higher the
20 applied voltage, the larger the leakage current that can be tolerated without completely losing the electrostatic clamping force from excessive current leakage through the semiconducting dielectric member **115**. However, the maximum operating voltages that can be used to electrostatically hold semiconductor substrates are limited to about 2000 volts, and if exceeded, can cause charge-up damage of the
25 active devices in the substrate **55**. Thus, the leakage current provided by the semiconducting material should be sufficiently low to retain electrostatic charge in the dielectric member **115**, during operation the chuck at voltage levels of about 100 to about 1500 volts. It has been discovered that optimal leakage currents from the dielectric member **115**, that provide quick charging response times, without damaging
30 the devices on the substrate, are at least about 0.001 mAmps/cm², and more preferably from about 0.002 mAmps/cm² to about 0.004 mAmps/cm². A suitable leakage current is achieved by controlling the resistivity of the semiconducting dielectric member **115**. Thus, preferably, the resistivity of the semiconducting dielectric member **115** is sufficiently low to allow conductance of a low amperage

leakage current that provides a quick charging time of less than about 3 seconds, and more preferably less than about 1 second. The semiconducting dielectric member **115** also has a resistivity sufficiently low to provide rapid dissipation of accumulated electrostatic charge when the voltage applied to the electrode **110** is turned off.

- 5 Preferably, the resistivity of the semiconducting dielectric member **115** is sufficiently low to allow accumulated electrostatic charge to substantially entirely discharge or dissipate in less than about 1 second, and more preferably in less than about 0.5 second. Conventional dielectric members typically have dechucking times of 5 to 10 seconds, which is about five to ten times longer than that provided by semiconducting
10 dielectric member of the present invention.

While a low resistance semiconducting dielectric member **115** is desirable for rapid chucking and dechucking, a chuck having an excessively low resistance dielectric member will allow excessive charge to leak out. The resistance
15 of the semiconducting dielectric member **115** needs to be sufficiently high to maintain a supply of electrostatic charge at the interface of the chuck **100** and substrate **55**, even though a portion of the electrostatic charge leaks or dissipates through the member **115**. Any leakage current allows electrostatic charge to continually dissipate from the dielectric member **115**. Thus, electrostatic charge must accumulate at the
20 dielectric/substrate interface at a rate equal to or greater than the rate of charge dissipation to provide an equilibrium mode in which a supply of accumulated electrostatic charge is maintained at the dielectric/substrate interface.

In a preferred version, the semiconducting dielectric member **115**
25 comprises a resistance in a preferred range of resistivity $\Delta\rho$ that provides such a combination of opposing properties. The resistivity range $\Delta\rho$ of the semiconducting dielectric member **115** is defined by (i) a first lower resistivity ρ_L that is sufficiently low to allow a leakage current to flow from the electrode when the operating voltage is applied to the electrode to form accumulated electrostatic charge at the interface of
30 the substrate **55** and the semiconducting dielectric member **115**; and (ii) a second higher resistivity ρ_H that is sufficiently high to maintain accumulated electrostatic charge at the interface during operation of the chuck without use of excessively high operating voltages that damage the substrate. The optimal range $\Delta\rho$ of resistivity of the semiconducting dielectric member **115** is preferably from about 5×10^9 to about

$8 \times 10^{10} \Omega \text{ cm}$, and more preferably from about 1×10^{10} to about $5 \times 10^{10} \Omega \text{ cm}$. This range of resistivity is substantially lower than conventional dielectric members which have resistivities exceeding $1 \times 10^{11} \Omega \text{ cm}$, and more often exceeding $1 \times 10^{13} \Omega \text{ cm}$.

5

The semiconducting dielectric member **115** having the described properties can be fabricated from ceramic materials, polymers, and mixtures thereof. Suitable ceramic materials include (i) oxides such as Al_2O_3 , BeO , SiO_2 , Ta_2O_5 , ZrO_2 , CaO , MgO , TiO_2 , BaTiO_3 , (ii) nitrides such as AlN , TiN , BN , Si_3N_4 , (iii) borides such as ZrB_2 , TiB_2 , VB_2 , W_2B_3 , LaB_6 , (iv) silicides such as MoSi_2 , WSi_x , or TiSi_x . Preferably, the semiconducting dielectric member **115** having a resistivity in the preferred range of resistivities of $\Delta\rho$ comprises a composition of aluminum oxide doped with (i) transition metals or metal oxides, such as for example, Ti , Cr , Mn , Co , Cu , TiO_2 , Cr_2O_3 , MnO_2 , CoO , CuO , and mixtures thereof; (ii) alkaline earth metals or oxides, such as for example, Ca , Mg , Sr , Ba , CaO , MgO , SrO , or BaO ; or (iii) a combined oxide formulation, such as for example, CaTiO_3 , MgTiO_3 , SrTiO_3 , and BaTiO_3 . The dopant material is added in a sufficient quantity to provide semiconducting properties to the aluminum oxide dielectric material. By semiconducting it is meant a material having a conductivity in between that of a metal and an insulator.

20

Preferably, the dielectric member **115** comprises a unitary body of multiple layers of semiconductor and/or insulating material enclosing the electrodes, each layer typically having a thickness of from about $10 \mu\text{m}$ to about $500 \mu\text{m}$. The dielectric member **115** comprises a cover layer that electrically isolates the substrate **55** from the electrode **110**, and a support layer which supports the electrode and electrically isolates the electrode **110** from a conductive electrode **110**. The material and thickness of the cover layer are selected to allow the DC voltage applied to the electrode to electrostatically hold the substrate by means of Coulombic or Johnson-Rahbek electrostatic attractive forces. The thickness of the layer covering the electrode is typically from about $100 \mu\text{m}$ to about $300 \mu\text{m}$. Preferably, material of the cover layer comprises a dielectric constant of at least about 2. Additionally, a protective coating (not shown) can be applied on the exposed surface of the dielectric member to protect the semiconductor layer from erosive processing environments

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A preferred composition of the semiconducting dielectric member comprises aluminum oxide doped with titanium oxide in a weight percent content of at least about 8 wt%, and preferably at least about 12 wt%. Whereas, pure aluminum oxide has a resistivity of $10^{14} \Omega \text{ cm}$ and a characteristic charging response time of about 10^3 seconds; the highly doped aluminum oxide has a resistivity typically ranging from about $5 \times 10^9 \Omega \text{ cm}$ to about $8 \times 10^{10} \Omega \text{ cm}$. It is believed that the low resistivity results from titanium-metal rich grains or grain boundaries that are formed in the aluminum oxide material, titanium-metal rich regions comprising Ti^{3+} in solid solution in the aluminum oxide structure. However, the resistivity can also be dependent upon microstructural factors other than Ti^{3+} formation, for example, formation of highly conductive $\text{Al}_x\text{Ti}_y\text{O}_z$ phases within the alumina grains or at grain boundary regions. Formation of highly conductive titanium-metal rich alumina grains is particularly prevalent when the $\text{TiO}_2\text{-Al}_2\text{O}_3$ mixture is exposed to an oxygen-deficient or reducing environment, such as an inert gas environment during fabrication.

The semiconducting dielectric member **115** operates by Johnsen-Rahbek forces providing a higher electrostatic clamping force for relatively low chuck voltages. The low chuck voltages reduce the potential for damage to active regions in the substrate **55**. Also, the lower chuck voltages reduce the risk of plasma generation at the dielectric/substrate interface. The semiconductor dielectric is sufficiently leaky that upon application of a voltage to the electrode, the semiconducting dielectric member allows rapid accumulation of electrostatic charge at the dielectric/substrate interface. Furthermore, the low resistance semiconducting layer **115** provides electrostatic charge dissipation response times of less than about 1 second, and more typically less than about 0.5 seconds, with little or no residual charge or sticking forces. The extremely low charging and charge dissipation response time provides rapid chucking and dechucking with the electrostatic holding force rising almost instantaneously with applied voltage, and decreasing almost instantaneously to zero when the applied voltage is turned off. Also, unlike conventional ceramic formulations, the resistivity of the highly doped alumina coatings did not appear to change during use at temperatures ranging from -10°C to 100°C . These novel and unexpected advantages of the semiconducting dielectric member **115** provide significant benefits for electrostatic chucks.

In yet another aspect of the invention, as shown in Figure 15, a composite dielectric member **115** comprising a first dielectric material **172** having first electrical properties; and a second dielectric material **174** having second electrical properties, is used to cover the electrode **110** (which is illustrated as a base **105** that serves as the electrode, but also includes the embedded electrode version). In a preferred configuration, the first dielectric material **172** is disposed over a central portion of the electrode **110** (which is substantially entirely covered by the substrate **55** during operation of the chuck **100**); and the second dielectric material **174** is disposed over a peripheral portion of the electrode **110** and comprises an annular rim extending around the first dielectric member. This configuration allows tailoring of the properties of the composite dielectric layers across the radial surface of the chuck. This is desirable to provide different electrical properties at the edge of the chuck which is closer to the plasma sheath than the center which is covered by the substrate.

The properties of the first and second dielectric members **172**, **174** are tailored to achieve different electrical properties at different portions of the chuck **100**. For example, the first dielectric member **172** can comprise a semiconducting material as described above. During operation of the chuck **100**, the first dielectric member is substantially entirely covered by the substrate which serves as a dielectric material that electrically insulates the semiconducting layer and reduces shorting between the semiconducting layer and the plasma. In this version, the second dielectric member **174** comprises an insulator that has a higher resistivity than the semiconducting dielectric member to prevent plasma discharge at the exposed peripheral portions of the chuck. The resistivity of the insulating second dielectric member **174** is sufficiently high to prevent electrical discharge or arcing between the surrounding plasma environment and the peripheral portions of the chuck electrode. Preferably, the second dielectric member **174** has a resistance of at least about $1 \times 10^{11} \Omega \text{ cm}$, and more preferably from about $10^{13} \Omega \text{ cm}$ to about $1 \times 10^{20} \Omega \text{ cm}$. This configuration prevent shorting and arcing between the leaky semiconducting dielectric member and the plasma and the resultant pinholes in the dielectric member that cause failure of the chuck. In another example, the composite dielectric coating **115** can comprise a first dielectric member **172** having a first dielectric breakdown strength, and a second dielectric member **174** having a second dielectric breakdown

strength. Preferably, the second dielectric breakdown strength is higher than the first dielectric breakdown strength to prevent plasma discharge or electrostatic charge neutralization at the peripheral edge of the chuck.

5 The composite dielectric member **115** can also be made from multiple vertically stacked layers. For example, a multilayer composite dielectric member **115** can comprise (i) an Al_2O_3 - TiO_2 layer providing semiconducting electrical properties; and (ii) a more insulative second layer, such as polyimide, Teflon®, SiO_2 , or ZrO_2 . For example, the multilayer structure can be tailored to provide increased electrostatic
10 charge retention at the top surface **170** of the chuck, and/or faster electrostatic charge accumulation and dissipation response times through the body of the dielectric member. This can be accomplished by forming a thin second dielectric member having a high resistivity over a first dielectric member having a lower resistivity. Because the electrostatic force is largely attributable to the charge concentrated near
15 the surface of the dielectric member **115**, such multilayer coatings, can provide excellent surface charge retention characteristics, without affecting charge dissipation from the underlying layer. The multiple dielectric members preferably comprise a combination of semiconducting and insulator dielectric members.

20 The semiconducting or composite dielectric member **115** can be formed by a variety of conventional methods, as apparent to those skilled in the art, including for example, isostatic pressing, thermal spraying, sputtering, CVD, PVD, solution coating, or sintering a ceramic block with the electrode **110** embedded therein; as would be apparent to those skilled in the art. In the methods described below, the
25 semiconducting dielectric member **115** is used to cover at least a portion of the electrically conductive base that serves as the electrode **110**, or is used to cover or entirely enclose an electrode **110** to form an electrostatic member that can be supported by the base.

30 A preferred method of forming a unitary dielectric member **115** with an embedded electrode uses a pressure forming apparatus, such as an autoclave, platen press or isostatic press. Isostatic presses are preferred because they apply a more uniform pressure on the dielectric member and electrode assembly. Typical isostatic press comprise a pressure resistant steel chamber having a diameter ranging from

about 1 to 10 feet. A pressurized fluid is used to apply pressure on an isostatic molding bag. A powdered precursor is prepared comprising a suitable ceramic compound as described above is mixed with an organic binder selected to burn off during sintering. The precursor is placed along with the electrode structure in the isostatic molding bag and the bag is inserted in the isostatic press. The fluid in the pressure chamber is pressurized to apply an isostatic pressure on the dielectric assembly. It is desirable to simultaneously remove air trapped in the isostatic molding bag using a vacuum pump to increase the cohesion of the powdered precursor. The unitary dielectric member/electrode assembly is removed from the molding bag and sintered to form a unitary dielectric with the electrode embedded. The gas flow conduits **150** are formed in the dielectric member by conventional techniques, such as drilling, boring, or milling. Preferably, at least some of the conduits **150** terminate at the periphery of the chuck **100**, to provide heat transfer gas to the peripheral edge of the substrate **55**.

15

After deposition, the surface of the dielectric member **115** is fine ground to obtain a highly flat surface to efficiently electrically and thermally couple the substrate **55** on the chuck **100**. In a typically high density plasma, the driving point RF bias impedance presented by the plasma is very low. To achieve uniform ion flux energy to the substrate **55** it is necessary to uniformly couple RF energy from the plasma through the substrate **55** to provide a constant plasma sheath voltage across the surface of the substrate **55**. Nonuniform plasma sheath voltages result different processing rates or attributes across the substrate surface. The uniformity of the plasma sheath voltage is a function of the impedance/area of the plasma sheath, the substrate **55**, the gap between the substrate **55** and the chuck **100**, and the chuck **100**. A nonuniform impedance or rough surface on the chuck **100** creates uneven impedances between the chuck and the substrate, resulting in nonuniform plasma sheath voltage. Thus, it is desirable for the chuck **100** to have a substantially flat and planar dielectric member **115** to provide uniform impedance in the gap between the dielectric member **115** and the substrate. Besides providing strong electrical coupling, a flat and smooth dielectric member also provides strongly thermally coupling and good heat transfer properties from the substrate **55** to the chuck **100**. Thus conventional diamond grinding wheels are used to grind the semiconducting dielectric

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member **115** to a surface roughness of about 0.007 ± 0.001 mm, which is typically less than about 30 rms.

Alternatively, the dielectric member **115** can comprise a layer of

5 dielectric material formed directly on the electrode **110** or electrode **110** using thermal spraying methods, such as for example, plasma glow discharge spraying, flame spraying, electric wire melting, electric-arc melting, and detonation gun techniques, as described below. Prior to use of the thermal spraying methods, the upper surface of the electrode **110** or base **105** (which to avoid repetition are collectively referred to

10 herein as electrode **110**), that is typically made of a conductive metal such as aluminum or copper, is abraded by grit blasting to provide a roughened surface that enhances adhesion of the dielectric member **115**. In the grit blasting process, the surface of the electrode **110** is blasted at a predetermined grit spray incidence angle. Furthermore, by rotating the base during blasting, microscopic grooves are formed

15 which undercut the aluminum surface to provide mechanical interlocking of a dielectric member that is subsequently formed on the grooved and undercut surface. In this process, the electrode **110** is fixed to a rotating turntable that rotates the electrode **110** around a centerline. The grit is blasted onto the surface of the electrode **110** using a nozzle oriented at an angle to the surface of the base. The nozzle travels from

20 the outer edge to the center of the base at a variable speed to maintain the depth and the pitch of the grit blasted grooves. Typically, the rate of nozzle travel increasing as the nozzle moves from the outer edge toward the center. For example, an aluminum electrode **110** was fixed to a turntable which rotated at about 20 to 30 revolutions per minute (rpm), and the angle of incidence of the nozzle relative to surface of the

25 aluminum electrode **110** was about 70° . A grit of particle size of about 60 to 80 mesh, was grit blasted using a paint removal type nozzle, onto the base. The height of the grit blasted grooves was about 0.025 mm (0.001 inch), and their pitch was about 0.073 mm (0.003 inch).

30 After preparation of the surface of the electrode **110**, a coating of semiconducting material is formed on the electrode **110**. Preferably, a thermal spraying process is used to apply the selected ceramic formulation. For example, an alumina-titania composition is sintered to form a homogeneous frit, and ground to form a fine particle sized ceramic powder having an average particle size ranging from

about 10 to about 100 μm . The spraying process partially melts and energetically impacts the ceramic powder onto the electrode **110**. Typically, the electrode **110** is maintained at a temperature of about 60°C to about 80°C, and the ceramic powder is thermally sprayed at an angle of about 80° to 90° (nearly perpendicular) to the surface of the base. The thermally sprayed coatings can bounce-off the surface, so it is important to apply the coating at a proper angle to the base to reduce microcracking and provide dense layers. The high kinetic energy of the molten fine ceramic particles provide a dense, low porosity, dielectric member having the desired semiconducting properties and low resistivity. The semiconducting dielectric member **115** should be sufficiently dense to completely electrically insulate the electrode **110** of the chuck **100**. A low or zero electrical resistance at any point in the semiconducting dielectric member **115** can result in an electrical short. Low electrical resistance can occur when the semiconducting dielectric member **115** is damaged during spraying, i.e., by large macroscopic cracks; or if the dielectric coating is too porous and allows plasma to permeate through the pores and electrically short the dielectric member **115**. After cooling, the peel strength of the thermally sprayed alumina/titania was tested using ASTM methods and found to have improved by about 20% over that obtained using other coating methods.

Different thermal spray methods of forming the semiconducting layer **115** will now be described. Referring to Figure 16, a plasma glow discharge spraying process uses a plasma gun **240** consists of a cone-shaped cathode **242** inside a cylindrical anode **244** which forms a nozzle. An ionizable inert gas, typically argon, argon/hydrogen, or argon/helium, is flowed through the plasma zone between the electrically biased anode and cathode where it is ionized to form a plasma. Ceramic powders injected into the plasma zone are accelerated and melted by the high temperature plasma. Molten droplets are propelled onto the electrode **110**, where they solidify and accumulate to form a thick, well-bonded, and dense semiconducting dielectric member **115**. The process has sufficient thermal energy to completely melt high temperature ceramic materials, such as alumina and/or titania.

In the flame spraying method, a highly combustible mixture of acetylene and oxygen is used to melt a sprayed ceramic powder sprayed through the flame. In this method, a high temperature flame is produced using a combustible mixture of

gases, for example acetylene and oxygen, as shown in Figure 17. A typical flame spraying gun **250** comprises a fuel supply **252** and an oxygen supply **254**. The oxygen enriched fuel mixture is ignited by a sparking means, such as a spark plug **256**. The resultant high velocity ignited gas melts the ceramic particles injected
5 through the nozzle **258** and the molten particles impinge on the electrode **110**. The flame spraying method provides a relatively low heat or energy input to the ceramic powder. The low kinetic energy ceramic particles travel relatively slowly from the flame to the surface of the electrode **110** allowing the particle to cool during travel. As a result of the cooling, and the relatively low kinetic energy impact on the
10 electrode **110** the solidified plasma-deactivating material comprises spherical ceramic particles that retain their shape, providing pores and tortuous pathways between the particles that provide a high surface area.

Another method comprises a detonation gun technique (not shown). In
15 this method, a rapidly expanding mixture of ignited gases imparts a high kinetic energy to powdered ceramic material that provides a dense coating on impact with the electrode **110**. In the detonation gun, a series of detonation explosion are used to provide extremely high energy molten ceramic particles that impact the electrode **110** to form a very dense ceramic material having novel electrical properties. The high
20 velocity detonation melts and expels the ceramic particles from a gun like nozzle directed toward the electrode **110**. Typically, the hot expanded gases comprise a velocity of about 600 m/sec (2000 ft/sec) to about 900 m/sec (3000 ft/sec), and a succession of such detonations provide the resultant coating thickness on the substrate.

25

Preferably, the dielectric member **115** is formed by an electric arc melting method, as shown in Figures 18 and 19. A typical electric arc melter comprises a circular ring-shaped cathode **262** with a hole **264** therethrough, and a needle-shaped anode **266** centered within the cathode (as shown in Figure 18) or
30 adjacent to the cathode (not shown). The fine ceramic powder from a source **268** is sprayed around the anode using carrier gas from a carrier gas supply **270**, at a feeding rate of about 2 to about 10 gm/min. The powdered ceramic material is transported by a carrier gas through the channels **272** on either side of the needle-shaped anode **266** and is directed through the opening **264** having a diameter of about 1 to 10 mm. An

electric arc **274** is formed by applying a voltage V sufficiently high to substantially entirely melt the ceramic powder being sprayed into the arc. The ceramic powder melts in the high temperature electric arc **274** and highly energetically impinges on the electrode **110**. Also, important in the electric arc melting process is the distance d between the ring-shaped cathode **262**, the anode nozzle **266**, and the substrate **55**, commonly referred to as the spray distance. The distance d between the arcing electrodes and the chuck electrode is selected so that the ceramic powder impinges on the chuck electrode in a substantially molten state.

The carrier gas that is used to transport the ceramic powder can be an inert gas, a reducing gas, or an oxidizing gas. A reducing gas can increase formation of non-stoichiometric transition metal compounds in the alumina to reduce the resistivity of the ceramic while retaining its mechanical properties. Also, oxidizing gas are generally undesirable because they cause excessive oxidation of the alumina resulting in high resistivity dielectric members **115**. Preferably, the carrier gas comprises a non-reactive gas, such as an inert gas, for example, argon, helium, or xenon. Most preferably, argon gas is used to transport the ceramic particles at a flow rate of about 20 to 100 l/min.

The ceramic powder sprayed into the electric arc **274** melts while passing through the highly energetic and extremely hot electric arc **274** to form molten droplets that impinge on the electrode **110**. The energized molten grains impinge on the base and rapidly solidify due to conduction and convection cooling at the incident surface. The in-flight convection cooling of the molten droplets is minimized by the high kinetic energy imparted to the molten droplets by the electric arc. This restricts grain growth and improves homogeneity by reducing segregation of impurities. Although the mechanism is not understood, it was discovered that the electric arc melting process provided flattened ceramic grains (schematically illustrated in Figure 19), small grain sizes, and grain boundary compositions that give rise to entirely different electrical and thermal properties, such as the controlled electrical resistivity desired in the semiconducting layer. Of primary importance is the droplet velocity and temperature, which are controlled by the ratio of the kinetic energy to heat input provided by the electric arc melting process to the ceramic powder traveling through the arc. The high kinetic energy and heat input provided to the

ceramic particles by the electric arc melting process results in a high speed "splatting" of molten particles on the surface of the electrode **110** causing spreading of the particles, rapid cooling from 500-600°C to room temperature, and solidification in about 15-20 microseconds. This provides a dense coating with the required

5 distribution of conductive titania species in the alumina composition. The electric arc melting methods provided highly dense $\text{Al}_2\text{O}_3/\text{TiO}_2$ compositions having resistivities of from 1 to $5 \times 10^{11} \Omega\text{-cm}$. Scanning electron microscope (SEM) photomicrographs showed dense coatings with homogeneously dispersed porosity of less than about 10%, and often less than about 5%.

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The thermally sprayed ceramic coatings form submicron microcracks **276** upon cooling and solidification that permit the dielectric member **115** to expand or stretch to conform with the differential thermal expansion between the dielectric member **115**, electrode **110**, and/or electrical isolators **200**, without forming large-

15 sized cracks or delaminating from the underlying electrode **110**. Large cracks allow plasma to enter through the microcracks **276** thereby damaging the electrode **110** and dielectric member **115**. However, small microcracking is desirable as long as the cracks are submicron sized, relatively uniformly distributed, and formed along inhomogeneous grains and grain boundaries without propagating through the entire

20 thickness of the dielectric member **115**. Such controlled microcracking prevents delamination and cracking-off of the dielectric member **115** from the thermal expansion stresses at high process temperatures. For example, microcracking prevents aluminum oxide containing dielectric member **115** (which has a thermal expansion close to that of pure alumina of about $4.3 \times 10^{-6} \text{ in/in/}^\circ\text{F}$) from delaminating

25 and separating from the underlying aluminum electrode **110** (which has a much higher thermal expansion of about $13 \times 10^{-6} \text{ in/in/}^\circ\text{F}$).

Although the present invention has been described in considerable detail with regard to the preferred version thereof, other versions are possible. For example,

30 the semiconducting dielectric member **115** can be used in other applications, and can be fabricated from equivalent compositions that provide quick chucking and dechucking response times. Also, the electrical isolator **200** can be fabricated in many other shapes and forms that are equivalent in function to the illustrative

structures herein. Therefore, the appended claims should not be limited to the description of the preferred versions contained herein.

What is claimed is:

1. An electrostatic chuck for holding a substrate in a plasma, the chuck comprising:

5 (a) a dielectric member covering an electrode, the dielectric member having a top surface for supporting the substrate;

(b) at least one conduit extending through one or more of the dielectric member and electrode, for providing gas to the top surface of the dielectric member; and

10 (c) an electrical isolator in the conduit, for reducing plasma formation in and around the conduit, substantially without blocking the passage of gas through the conduit.

2. The electrostatic chuck of claim 1 wherein the electrical isolator
15 comprises a coating of dielectric material on sidewalls of the conduit.

3. The electrostatic chuck of claim 1 wherein the electrical isolator comprises a preformed insert in the conduit, the insert having at least one continuous passageway that allows gas to flow through the insert.

20 4. The electrostatic chuck of claim 1 wherein the electrical isolator comprises a porous plug of dielectric material in the conduit.

5. The electrostatic chuck of claim 1 wherein the electrical isolator
25 comprises a plasma-deactivating material capable of reducing plasma formation in the conduit.

6. The electrostatic chuck of claim 5 wherein the plasma-deactivating material comprises continuous pore passageways that allow gas to flow
30 through the material.

7. The electrostatic chuck of claim 1 wherein the electrical isolator comprises aluminum oxide, aluminum nitride, titanium oxide, silicon dioxide, zirconium oxide, silicon carbide, silicon nitride, or mixtures thereof.

8. The electrostatic chuck of claim 7 wherein the electrical isolator comprises a dielectric material having a resistivity of from about 10^{11} to about 10^{20} Ω cm.

5 9. The electrostatic chuck of claim 1 wherein the dielectric member comprises a unitary body of dielectric material, and wherein the electrode is embedded in the unitary body.

10 10. The electrostatic chuck of claim 1 wherein the dielectric member comprises a coating of dielectric material covering the electrode.

11. An electrostatic chuck for holding a substrate in a plasma environment, the chuck comprising:

- 15 (a) a dielectric member covering an electrode, the dielectric member having a top surface for supporting a substrate;
- (b) at least one gas conduit extending through one or more of the dielectric member or electrode for providing gas to the top surface of the dielectric member; and
- 20 (c) a plasma-deactivating material in the gas conduit, the plasma-deactivating material provided for reducing plasma formation in or near the conduit.

12. The electrostatic chuck of claim 11 wherein the plasma-deactivating material comprises at least one of the following characteristics:

- 25 (i) continuous pore passageways extending therethrough, (ii) a surface area of at least about $20 \text{ cm}^2/\text{gm}$, or (iii) a volume percent porosity of at least about 10%.

13. The electrostatic chuck of claim 11 wherein the plasma-deactivating material is made from a material selected from the group consisting of
30 aluminum oxide, aluminum nitride, titanium oxide, silicon dioxide, zirconium oxide, silicon carbide, silicon nitride, and mixtures thereof.

14. The electrostatic chuck of claim 11 wherein the gas conduit comprises an outlet having non-vertical surfaces defining a tapered region shaped and sized to enhance adhesion of the plasma deactivating material.

5 15. A plasma-deactivating plug for electrically isolating a gas flow conduit in an electrostatic chuck from a plasma environment, the plasma-deactivating plug comprising:

(a) at least one continuous passageway therethrough that allows gas to flow through the conduit; and

10 (b) a surface area of at least about 20 cm²/gm.

16. The plasma-deactivating plug of claim 15 comprising dielectric material composed of aluminum oxide, aluminum nitride, titanium oxide, silicon dioxide, zirconium oxide, silicon carbide, silicon nitride, or mixtures thereof.

15

17. The plasma-deactivating plug of claim 15 comprising dielectric material shaped and sized to fit a gas flow conduit of an electrostatic chuck.

18. An electrostatic chuck for holding a substrate in a plasma in a process chamber, the chuck comprising:

20

(a) a dielectric member covering an electrode, the dielectric member having a top surface for supporting the substrate;

(b) at least one heat transfer gas flow conduit extending through one or more of the dielectric member and electrode, the conduit comprising

25 (i) an inlet for receiving heat transfer gas from a heat transfer gas supply, and (ii) an outlet for providing the heat transfer gas to the top surface of the dielectric member, the outlet having sidewalls; and

(c) a plasma-deactivating coating on a portion of the sidewalls of the outlet of the gas flow conduit, the plasma deactivating coating provided for
30 reducing plasma formation in the conduit substantially without blocking the passage of heat transfer gas through the conduit.

19. An electrostatic chuck for holding a substrate in a plasma in a process chamber, the chuck comprising:

(a) a dielectric member covering an electrode, the dielectric member having a top surface for supporting the substrate,

5 (b) at least one heat transfer gas conduit extending through one or more of the dielectric member and electrode, the conduit comprising (i) an inlet for receiving heat transfer gas from a heat transfer gas supply, and (ii) an outlet for delivering the heat transfer gas to the top surface of the dielectric member; and

10 (c) a preformed plasma-deactivating insert in the outlet of the gas flow conduit for reducing plasma formation in the conduit substantially without blocking the passage of heat transfer gas through the conduit.

20. An electrostatic chuck for holding a substrate in a process chamber, the chuck comprising a dielectric covering an electrode, the dielectric having
15 at least one gas flow conduit extending therethrough, the conduit comprising a porous material having pores for passage of gas therethrough.

21. The electrostatic chuck of claim 20 wherein the porous material is shaped as a plug at the outlet of the conduit.

20 22. The electrostatic chuck of claim 20 wherein the porous material defines an axial or circumferential hole for the passage of gas therethrough.

23. The electrostatic chuck of claim 20 wherein the porous material
25 comprises aluminum oxide, aluminum nitride, titanium oxide, silicon dioxide, zirconium oxide, silicon carbide, silicon nitride, or mixtures thereof.

24. The electrostatic chuck of claim 20 wherein the gas flow conduit
30 of the electrostatic chuck comprises an outlet having non-vertical sidewalls that define a tapered region, and wherein the porous material is shaped to fill the tapered region of the outlet.

25. The electrostatic chuck of claim 20 wherein the porous material comprises at least one of the following characteristics: (i) continuous pores extending therethrough, (ii) a surface area of at least about 20 cm²/gm, or (iii) a volume percent porosity of at least about 10%.

5

26. An electrostatic chuck for holding a substrate in a plasma environment, the chuck comprising:

- (a) an electrically conductive base;
- (b) a thermal-sprayed dielectric member on the base, the
10 dielectric member having a top surface for supporting the substrate; and
- (c) at least one heat transfer gas conduit extending through the base to provide heat transfer gas to the top surface of the dielectric member, the conduit comprising an outlet having non-vertical surfaces.

15

27. The electrostatic chuck of claim 26 wherein the non-vertical surfaces of the outlet are tapered at an sufficient angle relative to the plane of the top surface of the dielectric member to provide increased adhesion of the dielectric member onto the base.

20

28. The electrostatic chuck of claim 27 wherein the non-vertical surfaces of the conduit outlet are tapered at an angle of at least about 15° relative to the plane of the top surface of the dielectric member.

29. The electrostatic chuck of claim 26 wherein plasma-deactivating
25 material in the outlet of the conduit reduces plasma formation in the conduit in the plasma environment.

30. The electrostatic chuck of claim 29 wherein the plasma-deactivating material comprises at least one of the following characteristics:

30

- (i) a surface area of at least about 20 cm²/gm;
- (ii) a volume percent porosity of at least about 10%; or
- (iii) continuous pore passageways extending therethrough.

31. The electrostatic chuck of claim 29 wherein the plasma-deactivating material comprises a porous ceramic material selected from the group consisting of aluminum oxide, aluminum nitride, silicon dioxide, silicon carbide, silicon nitride, and mixtures thereof.

5

32. A method of forming an electrostatic chuck for holding a substrate in a plasma, the method comprising the steps of:

(a) forming at least one gas flow conduit extending through a dielectric member covering an electrode, the conduit comprising (i) an inlet for
10 receiving gas from a gas supply, and (ii) an outlet for delivering the gas to a top surface of the dielectric member; and

(b) forming an electrical isolator in the outlet of the gas flow conduit to electrically isolate gas passing through the outlet of the conduit from a plasma, substantially without blocking the passage of gas through the conduit.

15

33. The method of claim 32 wherein step (b) comprises at least one of the following steps: (i) coating a dielectric material on sidewalls of the gas flow conduit, (ii) positioning a preformed insert in the gas flow conduit, the insert having at least one continuous passageway that allows gas to flow therethrough, or (iii) forming
20 a porous plug of dielectric material in the gas flow conduit.

34. The method of claim 32 wherein the dielectric member comprises a unitary body of semiconducting dielectric material, and wherein the electrode is embedded in the unitary body.

25

35. A method of forming an electrostatic chuck comprising the steps of:

(a) forming a metal plate electrode having an upper surface, and a heat transfer gas flow conduit extending therethrough;

(b) forming an electrical isolator in the conduit, the electrical isolator comprising at least one continuous passageway to allow passage of heat transfer gas through the conduit; and

(c) forming a dielectric member covering the upper surface of the electrode to expose the passageway in the electrical isolator.

30

36. The method of claim 35 wherein step (b) comprises the steps of:

- (i) inserting a masking pin into the conduit in the electrode;
- (ii) forming the electrical isolator by depositing dielectric

material on a surface of the conduit surrounding the masking pin; and

- 5 (iii) removing the masking pin from the conduit.

37. The method of claim 35 wherein step (b) comprises the steps of:

- (i) fabricating an electrical isolator insert sized to fit in the

conduit of the electrode;

- 10 (ii) inserting the electrical isolator into the conduit so that an apex of the electrical isolator extends out of the electrode; and

(iii) removing the apex of the electrical isolator by a method selected from the group consisting of grinding and ablating.

38. The method of claim 35 wherein step (c) comprises the steps of:

- (i) forming a semiconducting dielectric member on the upper surface of the electrode so that the semiconducting dielectric member substantially covers the electrical isolator; and

- 15 (ii) removing a top surface of the semiconducting dielectric member until the passageway in the electrical isolator is exposed.

39. An electrostatic chuck for holding a substrate in a plasma process chamber, the chuck comprising:

- (a) an electrode;

- 25 (b) a dielectric member on the electrode, the dielectric member having a top surface for supporting the substrate;

(c) at least one gas flow conduit extending through the electrode and dielectric member, the conduit comprising (i) an inlet for receiving gas from a gas supply, and (ii) an outlet for delivering the gas to the top surface of the

30 dielectric member; and

(d) an electrical isolator in the outlet of the gas flow conduit for electrically isolating the outlet of the conduit from the electrode substantially without blocking the passage of gas through the conduit, the electrical isolator comprising one or more of (i) a dielectric coating on sidewalls of the gas flow conduit,

(ii) a preformed insert sized to fit in the gas flow conduit, or (iii) a porous plug substantially filling the outlet of the gas flow conduit, the plug having at least one continuous passageway that allows gas to flow through the plug.

5 40. The electrostatic chuck of claim 39 wherein the electrical isolator comprises a plasma-deactivating material for reducing plasma formation in the conduit.

10 41. The electrostatic chuck of claim 40 wherein the plasma-deactivating material comprises continuous pore passageways that allow gas to flow through the material.

 42. A rapidly charging and discharging electrostatic chuck for holding a substrate, the chuck comprising:

15 (a) an electrode; and
 (b) a semiconducting dielectric layer covering at least a portion of the electrode, the semiconducting dielectric layer having an electrical resistance of from about 5×10^9 to about $8 \times 10^{10} \Omega \text{ cm}$.

20 43. The electrostatic chuck of claim 42 wherein the semiconducting dielectric layer comprises an electrical resistance sufficiently low to allow accumulation of electrostatic charge in the semiconducting dielectric layer, and upon termination of the voltage applied to the chuck allow dissipation of the accumulated electrostatic charge in less than about 1 second.

25 44. The electrostatic chuck of claim 42 wherein the semiconducting dielectric layer comprises a resistivity of from about 1×10^{10} to about $5 \times 10^{10} \Omega \text{ cm}$.

30 45. The electrostatic chuck of claim 42 wherein the semiconducting dielectric layer comprise aluminum oxide mixed with at least about 8 wt% titanium oxide.

 46. A process chamber for processing a substrate in a high density plasma, the process chamber comprising the electrostatic chuck of claim 42.

47. The electrostatic chuck of claim 42 wherein a chuck further comprises:

- (i) at least one heat transfer fluid conduit extending through the electrode to allow passage of heat transfer fluid to the top surface of the semiconducting dielectric layer; and
- (ii) a plasma-deactivating material in an outlet of the conduit, the plasma-deactivating material capable of reducing plasma formation in the conduit in a plasma environment.

48. An electrostatic chuck for rapidly chucking and dechucking a substrate, the chuck comprising:

- (a) an electrode;
- (b) a semiconducting dielectric layer covering at least a portion of an electrode, the semiconducting dielectric characterized by a resistivity in a range $\Delta\rho$ defined by:

(1) a first lower resistivity ρ_L sufficiently low to provide a leakage current from a voltage applied to the electrode to cause electrostatic charge to accumulate in the semiconducting dielectric layer, and to allow the accumulated electrostatic charge to dissipate in less than about 1 second upon termination of the voltage applied to the electrode; and

(2) a second higher resistivity ρ_H sufficiently high to maintain accumulated electrostatic charge in the semiconducting dielectric layer.

49. The electrostatic chuck of claim 48 wherein the first lower resistivity ρ_L is about $5 \times 10^9 \Omega \text{ cm}$, and the second higher resistivity ρ_H is about $8 \times 10^{10} \Omega \text{ cm}$.

50. The electrostatic chuck of claim 48 wherein the first lower resistivity ρ_L is about $1 \times 10^{10} \Omega \text{ cm}$, and the second higher resistivity ρ_H is about $5 \times 10^{10} \Omega \text{ cm}$.

51. The electrostatic chuck of claim 48 wherein the semiconducting dielectric layer comprises aluminum oxide, aluminum nitride, silicon dioxide, silicon carbide, silicon nitride, titanium oxide, zirconium oxide, or mixtures thereof.

52. The electrostatic chuck of claim 48 wherein the semiconducting dielectric layer comprise aluminum oxide mixed with at least about 8 wt% titanium oxide.

5 53. The electrostatic chuck of claim 48 wherein the chuck further comprises:

(i) at least one heat transfer fluid conduit extending through one or more of the semiconducting dielectric layer and electrode, the conduit provided to allow passage of heat transfer fluid to the top surface of the semiconducting

10 dielectric layer; and

(ii) a plasma-deactivating material in an outlet of the conduit for reducing plasma formation in the conduit in a plasma environment.

54. An electrostatic chuck for holding a substrate using electrostatic
15 charge without discharging a surrounding plasma, the chuck comprising:

(a) an electrode; and

(b) a composite dielectric layer covering the electrode, the composite dielectric layer comprising: (i) a first dielectric material covering a central portion of the electrode; and (ii) a second dielectric material covering a peripheral
20 portion of the electrode, the second dielectric material comprising an annular rim extending around the first dielectric material.

55. The electrostatic chuck of claim 54 wherein the first dielectric material comprises a semiconducting material having a resistance of from about $5 \times 10^9 \Omega \text{ cm}$ to about $8 \times 10^{10} \Omega \text{ cm}$.
25

56. The electrostatic chuck of claim 54 wherein the second dielectric material comprises an insulator having a resistivity of from about 1×10^{11} to about $1 \times 10^{20} \Omega \text{ cm}$.

30

57. The electrostatic chuck of claim 54 wherein the first dielectric material comprise aluminum oxide mixed with at least about 8 wt% titanium oxide.

58. The electrostatic chuck of claim 54 wherein the chuck further comprises:

- (i) at least one heat transfer fluid conduit extending through one or more of the composite dielectric layer or electrode to allow passage of heat transfer fluid to the surface of the composite dielectric layer; and
- (ii) a plasma-deactivating material in an outlet of the conduit for reducing plasma formation in the conduit in a plasma environment.

59. An electrostatic chuck for rapidly chucking and dechucking a substrate held thereon by electrostatic charge, substantially without discharging a surrounding plasma, the chuck comprising:

- (a) an electrode; and
- (b) a composite dielectric covering the electrode, the composite dielectric having a top surface for supporting the substrate, and

(1) a semiconductor dielectric covering a central portion of the electrode, the semiconducting dielectric having a resistivity sufficiently low to allow rapid accumulation and dissipation of electrostatic charge therethrough; and

(2) an insulator dielectric covering a peripheral portion of the electrode, the insulator dielectric having a resistivity sufficiently high to substantially preclude plasma discharge therethrough.

60. The electrostatic chuck of claim 59 wherein the semiconductor dielectric comprises a resistivity of from about $5 \times 10^9 \Omega \text{ cm}$ to about $8 \times 10^{10} \Omega \text{ cm}$.

61. The electrostatic chuck of claim 59 wherein the insulator dielectric comprises a resistivity of from about 1×10^{11} to about $1 \times 10^{20} \Omega \text{ cm}$.

62. The electrostatic chuck of claim 59 wherein the semiconductor dielectric comprises aluminum oxide mixed with at least about 8 wt% titanium oxide.

63. A process for forming an electrostatic chuck comprising the steps of:

(a) mounting a chuck in facing relationship to arcing electrodes;

5 (b) forming an electrical arc between the arcing electrodes;

(c) flowing an inert gas stream through the electrical arc to absorb heat from the electrical arc; and

(d) spraying ceramic powder into the hot inert gas stream so that the ceramic powder melts in the electrical arc and energetically impinges on the
10 chuck to form a dense, low resistivity, semiconducting dielectric layer adhered to an electrode of the chuck, the semiconducting dielectric layer having by an electrical resistance of from about 5×10^9 to about $8 \times 10^{10} \Omega \text{ cm}$

64. The process of claim 63 wherein the electrical resistance of the
15 semiconducting dielectric layer is sufficiently low to allow accumulation of electrostatic charge therein, and dissipation of the accumulated electrostatic charge in less than about 1 second.

65. The process of claim 63 wherein a voltage V applied to the arcing
20 electrodes to form the electrical arc is sufficiently high that the electrical arc reaches temperatures that melt substantially all the ceramic powder sprayed into the electrical arc.

66. The process of claim 63 wherein a distance d between the arcing
25 electrodes and the chuck is selected so that the ceramic powder impinges on the chuck in a substantially molten state.

67. The process of claim 66 wherein the distance d is from about 50
to 400 mm.

30

68. The process of claim 63 wherein the ceramic powder comprise aluminum oxide mixed with at least about 8 wt% titanium oxide.

69. An electrostatic chuck for holding a substrate in a plasma, the chuck comprising:

(a) a dielectric member covering an electrode, the dielectric member having a top surface for supporting the substrate;

5 (b) at least one gas flow passageway extending through one or more of the dielectric member and electrode, the passageway comprising a dimension sufficiently small to preclude plasma formation in therein.

70. The electrostatic chuck of claim 69 wherein the gas flow
10 passageway comprises an outlet for delivering gas to the top surface of the dielectric member, the outlet having an inner diameter equal to or less than about 0.4 mm.

71. The electrostatic chuck of claim 70 wherein the diameter of the outlet is equal to or less than about 0.25 mm.

15

72. The electrostatic chuck of claim 69 wherein the gas flow passageway is formed in an insert positioned in a conduit in the dielectric member or electrode.

20 73. The electrostatic chuck of claim 72 wherein the dielectric member comprises aluminum oxide, aluminum nitride, titanium oxide, silicon dioxide, zirconium oxide, silicon carbide, silicon nitride, or mixtures thereof.

25 74. An electrostatic chuck for holding a substrate in a plasma, the chuck comprising:

(a) a dielectric member covering an electrode, the dielectric member having a top surface for supporting the substrate;

(b) at least one conduit extending through one or more of the dielectric member and electrode; and

30 (c) a tubular insert in the conduit, the tubular insert having a gas flow passageway with a diameter sufficiently small to substantially preclude plasma formation in the passageway.

75. The electrostatic chuck of claim 74 wherein the gas flow passageway comprises an outlet for delivering gas to the top surface of the dielectric member, the outlet having an inner diameter equal to or less than about 0.4 mm.

5 76. The electrostatic chuck of claim 75 wherein the outlet comprises a dimension that is equal to or less than about 0.25 mm.

77. The electrostatic chuck of claim 74 wherein the tubular insert comprises an outwardly extending ledge sized to hold the tubular insert in the conduit.

10

78. The electrostatic chuck of claim 74 wherein the thickness of the ledge is selected to hold the electrostatic chuck at a predetermined distance from a metal base during bonding of the electrostatic chuck to the metal base.

15 79. The electrostatic chuck of claim 74 wherein the dielectric member comprises aluminum nitride, titanium oxide, silicon dioxide, zirconium oxide, silicon carbide, silicon nitride, or mixtures thereof.

20 80. An electrostatic chuck for holding a substrate in a plasma, the chuck comprising:

(a) a dielectric member covering an electrode, the dielectric member having a top surface for supporting the substrate, and having at least one gas flow conduit extending therethrough; and

25 (b) an electrical isolator in the gas flow conduit for electrically isolating the gas in the conduit from the plasma substantially without blocking the passage of gas through the conduit, the electrical isolator comprising an electrical lead embedded therein.

30 81. The electrostatic chuck of claim 80 wherein the electrical lead of the electrical isolator is electrically connected to a ground potential.

82. The electrostatic chuck of claim 80 wherein the electrical lead of the electrical isolator is electrically connected to a conductor below the chuck.

83. The electrostatic chuck of claim 80 wherein the electrical isolator comprises a preformed insert in the gas flow conduit that defines at least one continuous passageway that allows gas to flow through the insert, and wherein the electrical lead is embedded in the preformed insert.

5

84. The electrostatic chuck of claim 80 wherein the electrical isolator comprises a porous dielectric material composed of aluminum oxide, aluminum nitride, titanium oxide, silicon dioxide, zirconium oxide, silicon carbide, silicon nitride, or mixtures thereof.

10

85. The electrostatic chuck of claim 84 wherein the electrical isolator comprises a dielectric material having a resistivity of from about 10^{11} to about 10^{20} Ω cm.

15

86. An electrostatic chuck for holding a substrate in a plasma, the chuck comprising:

(a) a dielectric member covering an electrode, the dielectric member having a top surface for supporting the substrate, and having at least one gas flow conduit extending therethrough; and

20

(b) an electrical isolator in the gas flow conduit for electrically isolating the gas in the conduit from the plasma, the electrical isolator comprising an annular opening extending circumferentially around the isolator, the annular opening sized to allow passage of gas therethrough while reducing plasma formation in and adjacent to the opening.

25

87. The electrostatic chuck of claim 86 wherein the electrical isolator comprises a ceramic insert surrounded by a polymer sleeve.

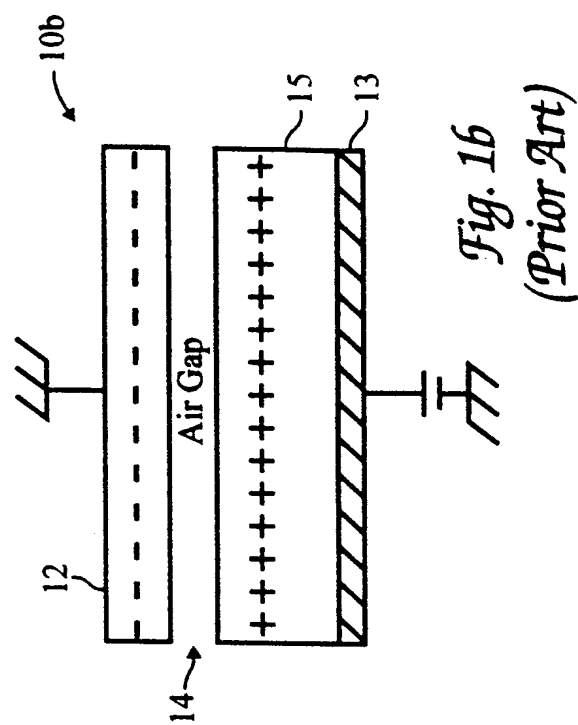
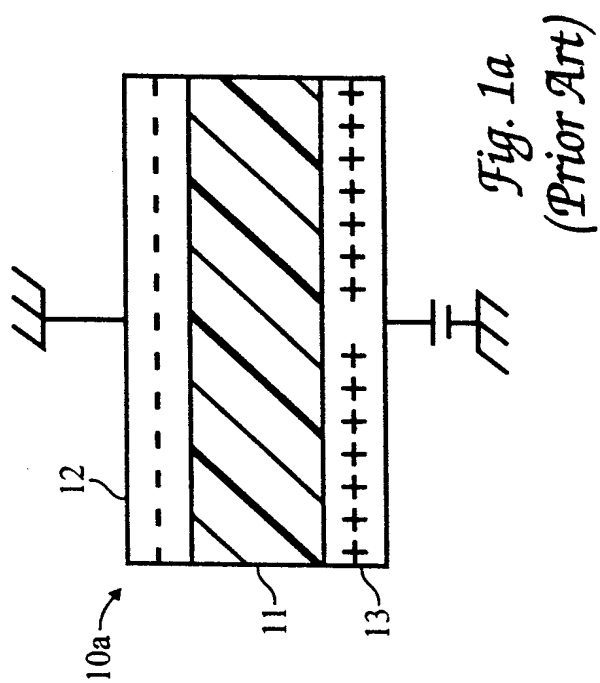
88. The electrostatic chuck of claim 86 wherein the polymer sleeve
30 comprises Teflon or silicone.

89. The electrostatic chuck of claim 86 wherein the electrical isolator further comprises an electrical lead that is electrically connected to a conductor below the chuck.

90. The electrostatic chuck of claim 86 wherein the electrical isolator comprises a porous dielectric material composed of aluminum oxide, aluminum nitride, titanium oxide, silicon dioxide, zirconium oxide, silicon carbide, silicon nitride, or mixtures thereof.

5

91. The electrostatic chuck of claim 86 wherein the electrical isolator comprises a dielectric material having a resistivity of from about 10^{11} to about $10^{20} \Omega$ cm.



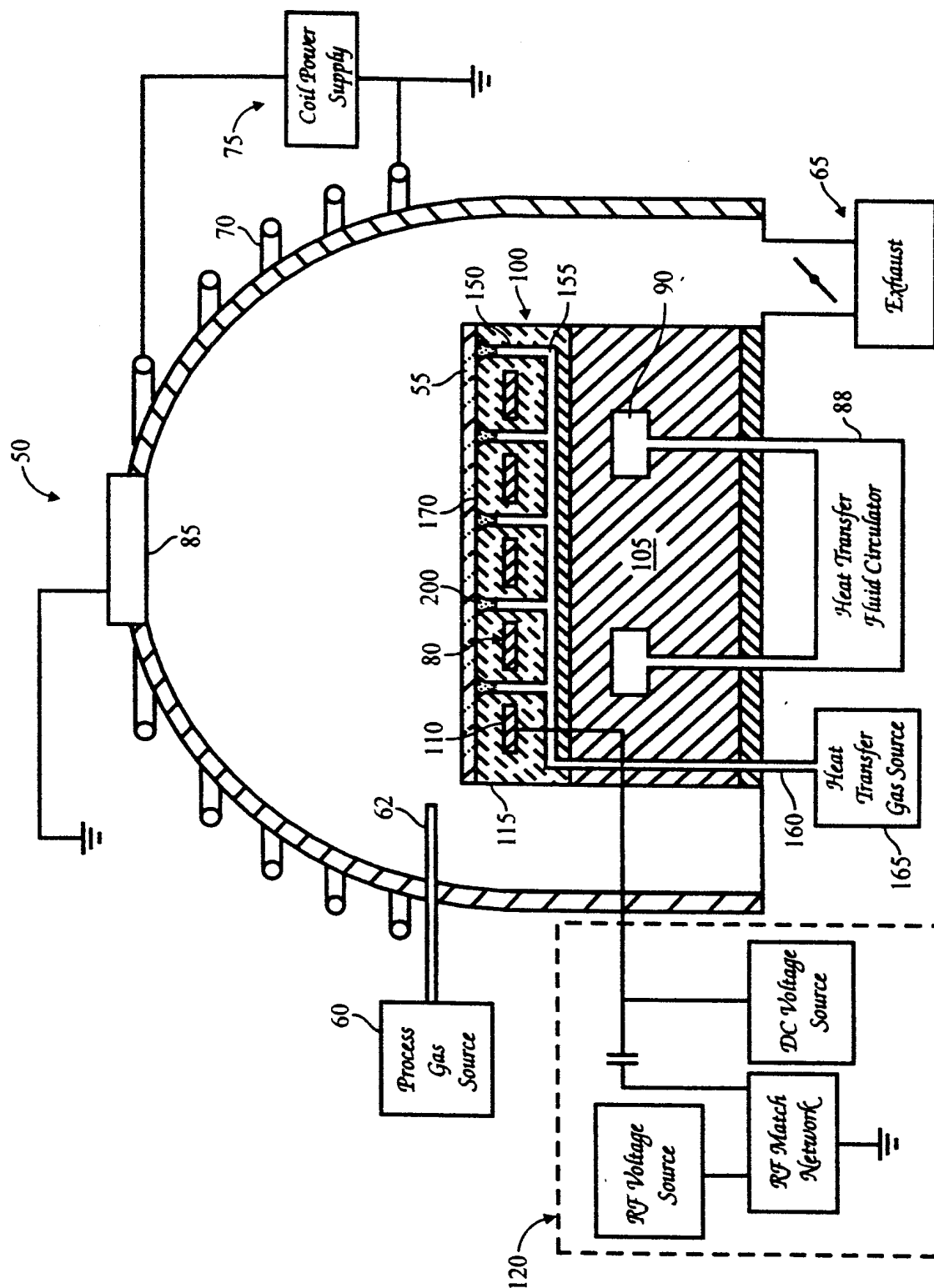
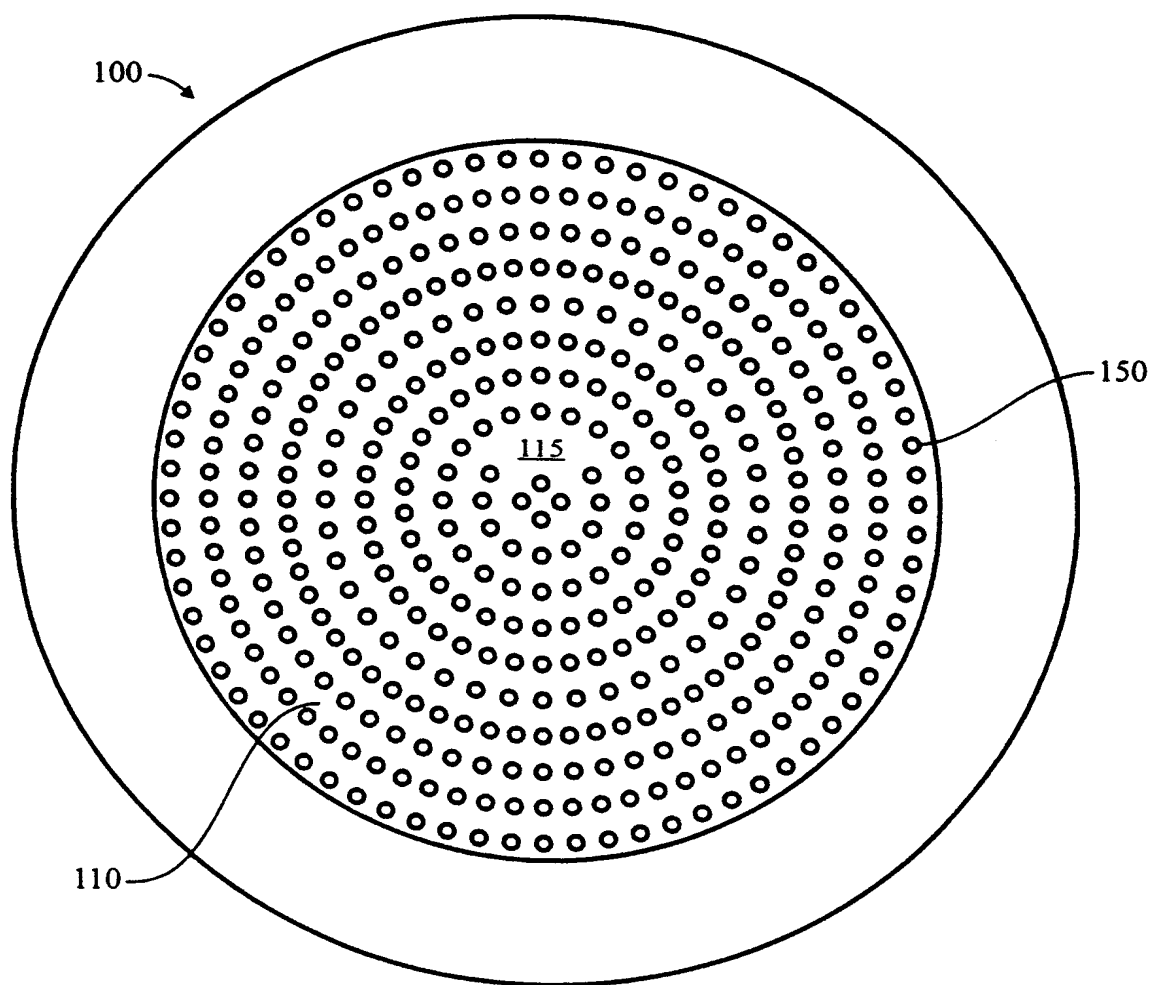
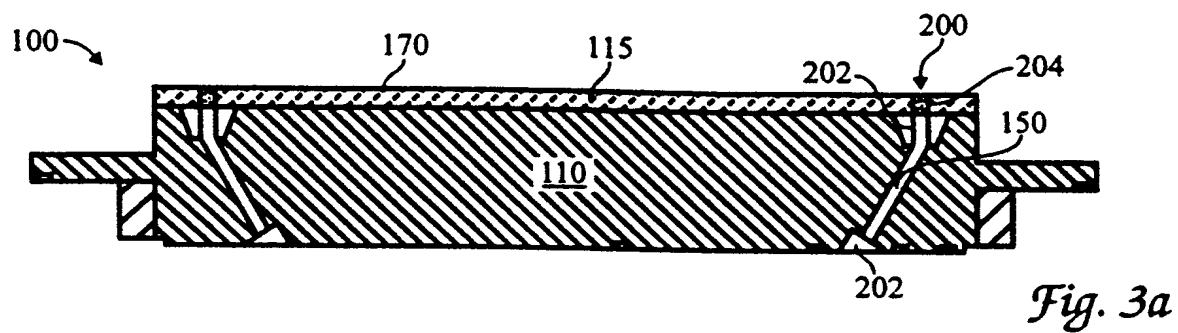


Fig. 2

*Fig. 3b*

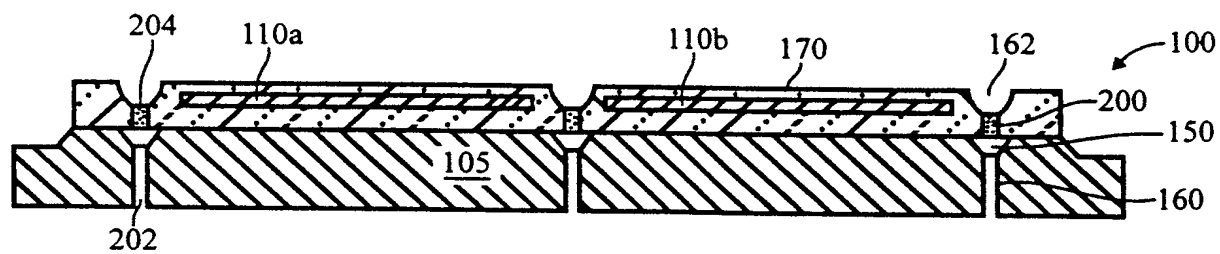
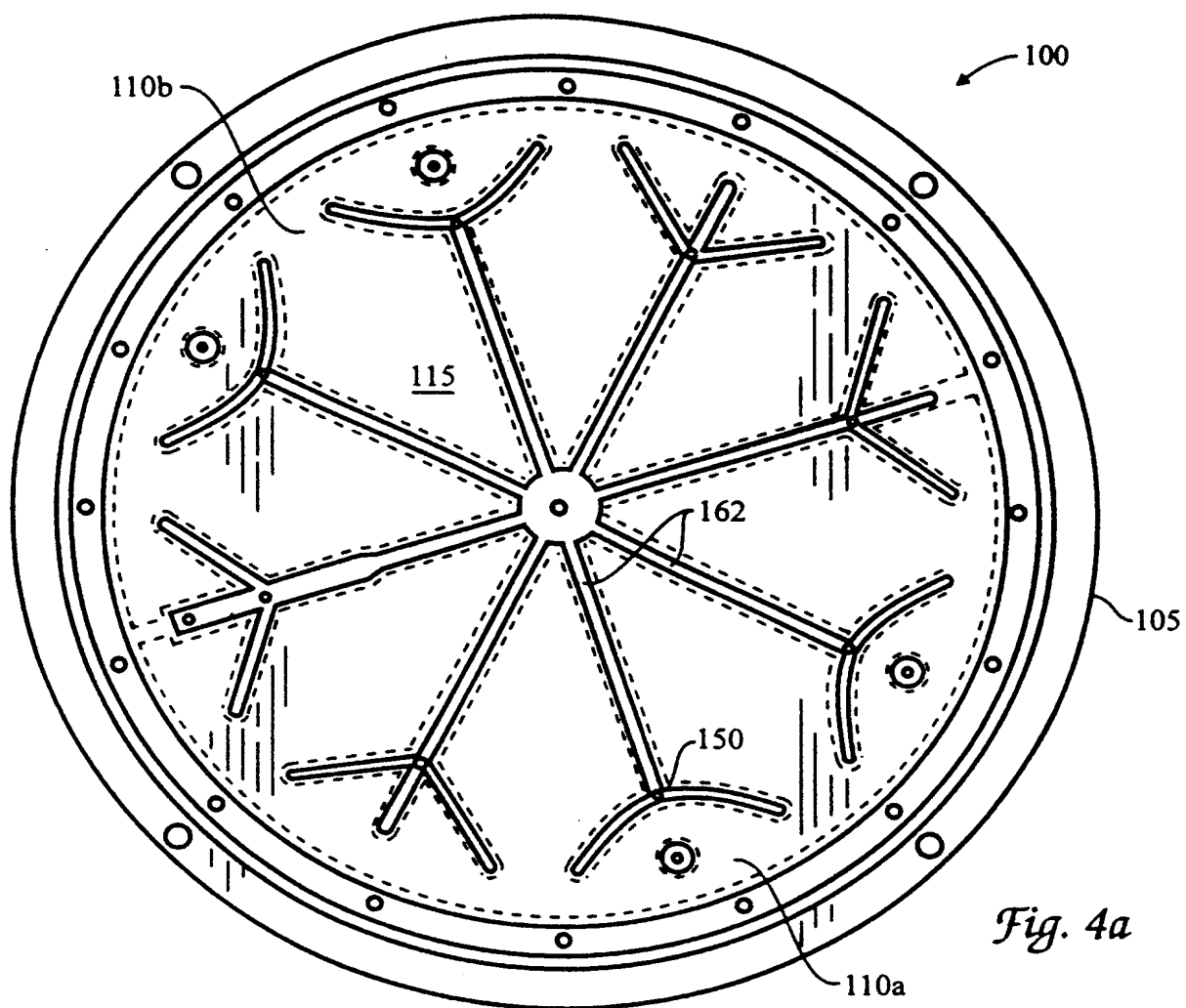
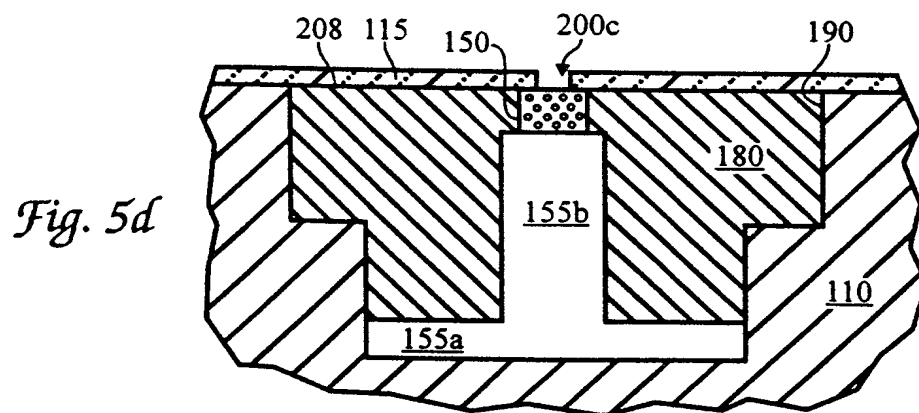
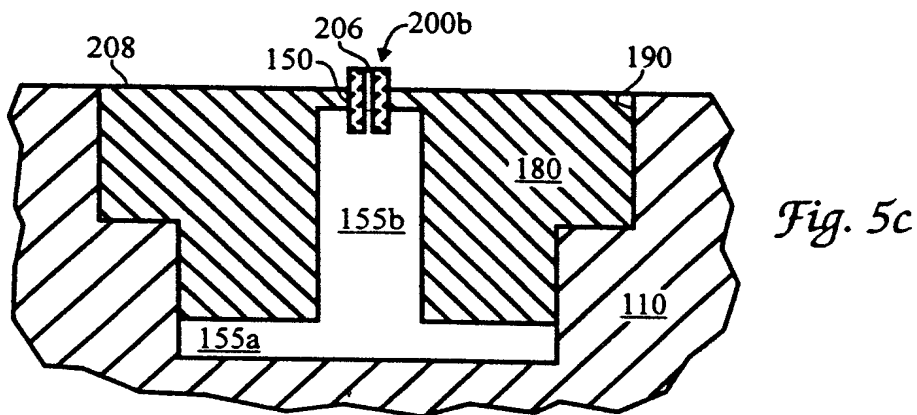
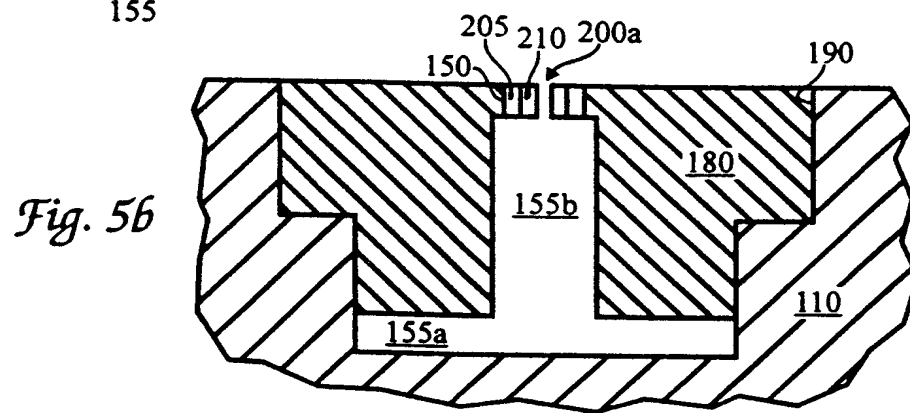
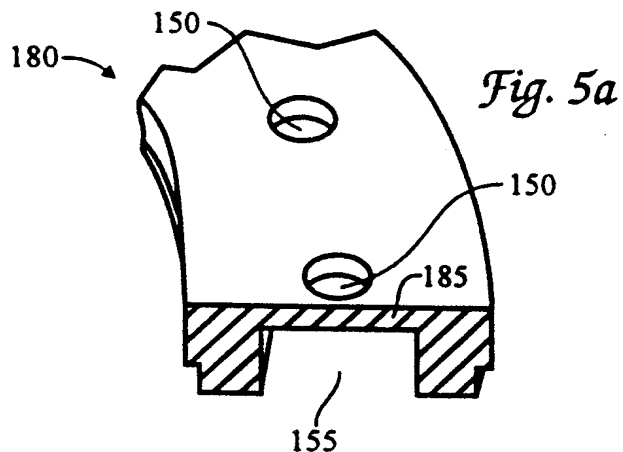
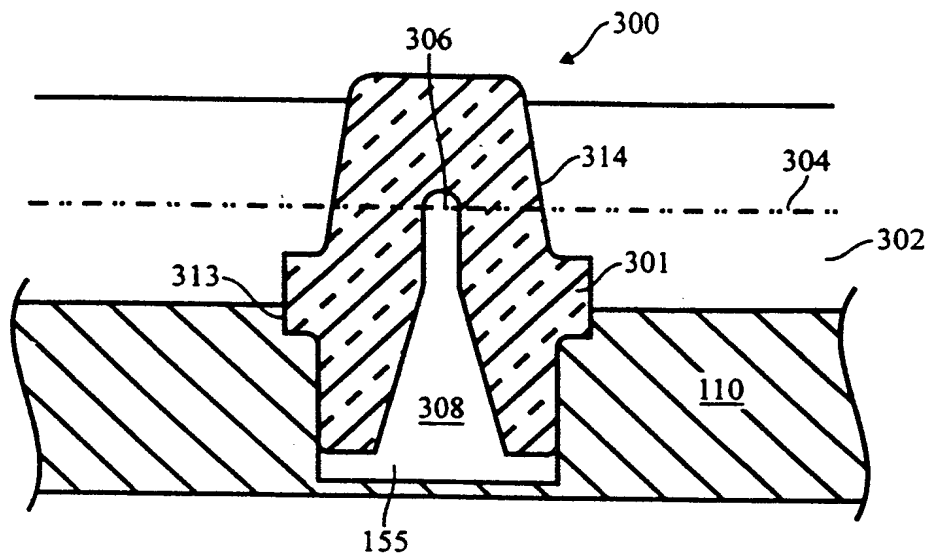
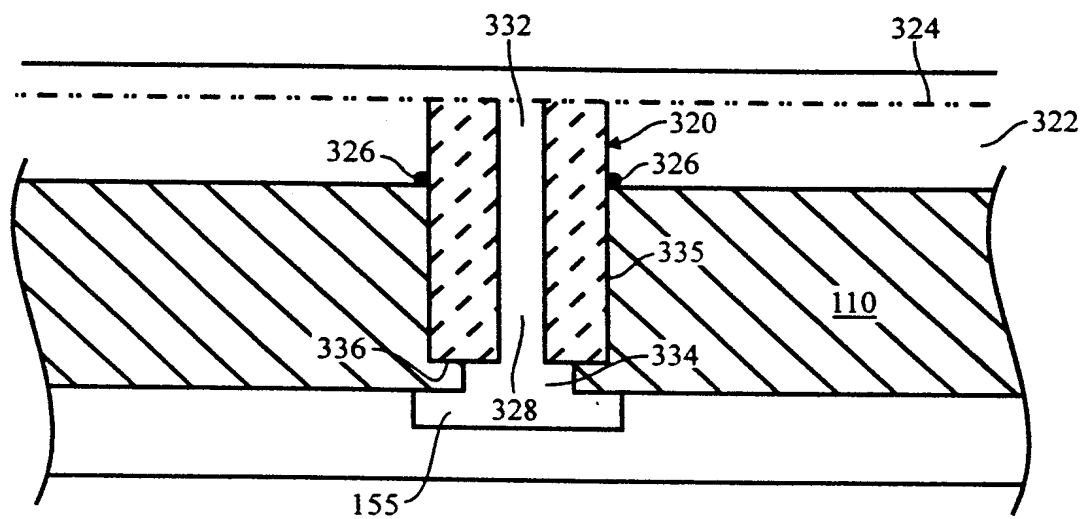
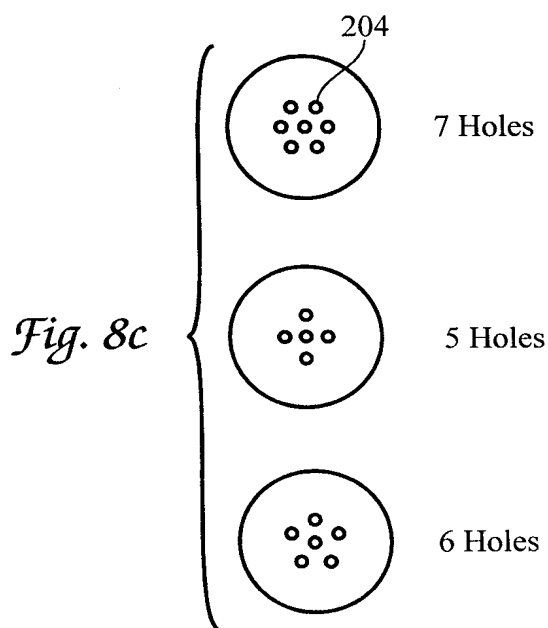
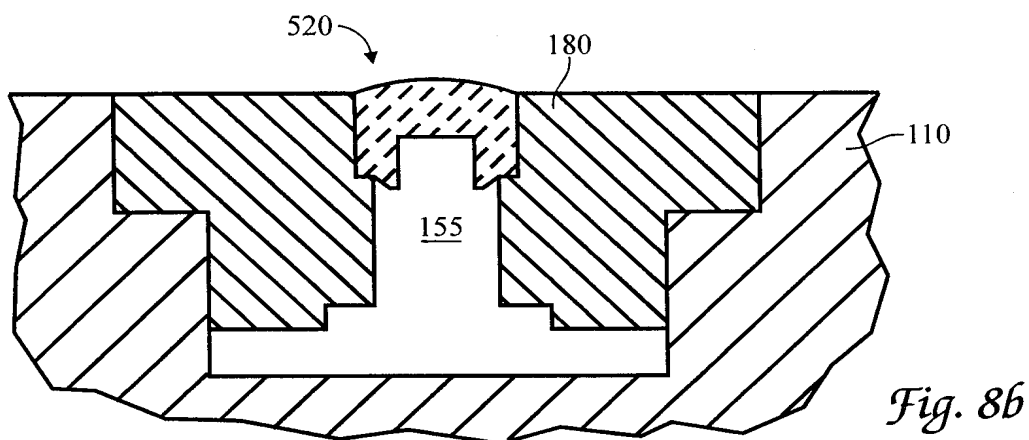
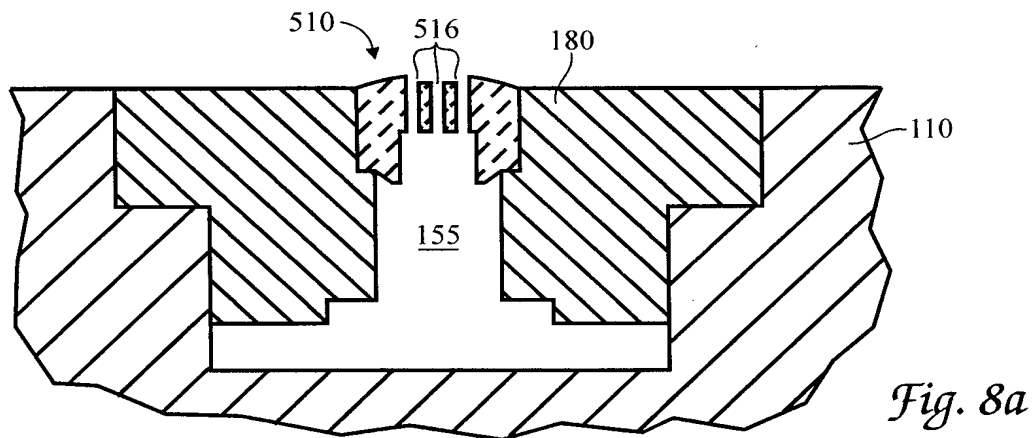
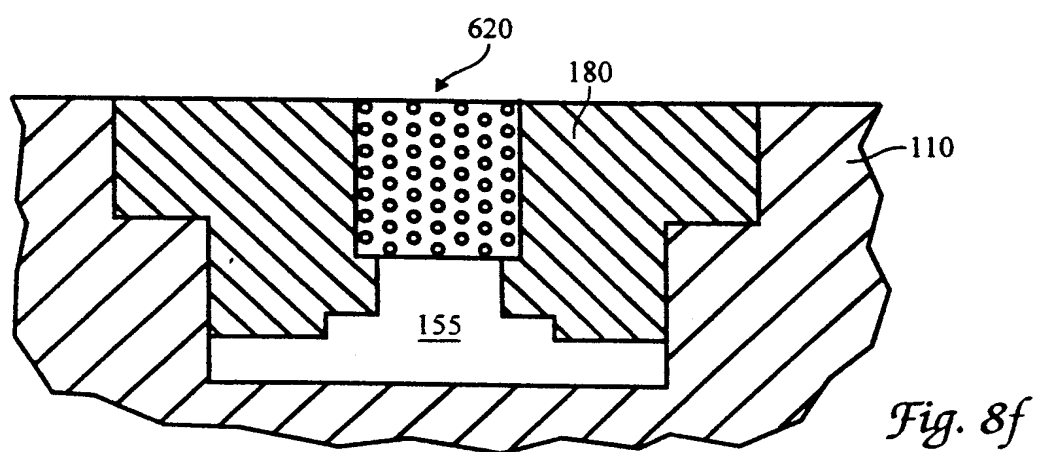
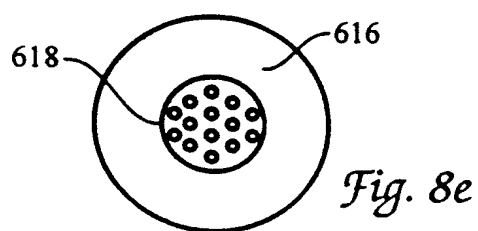
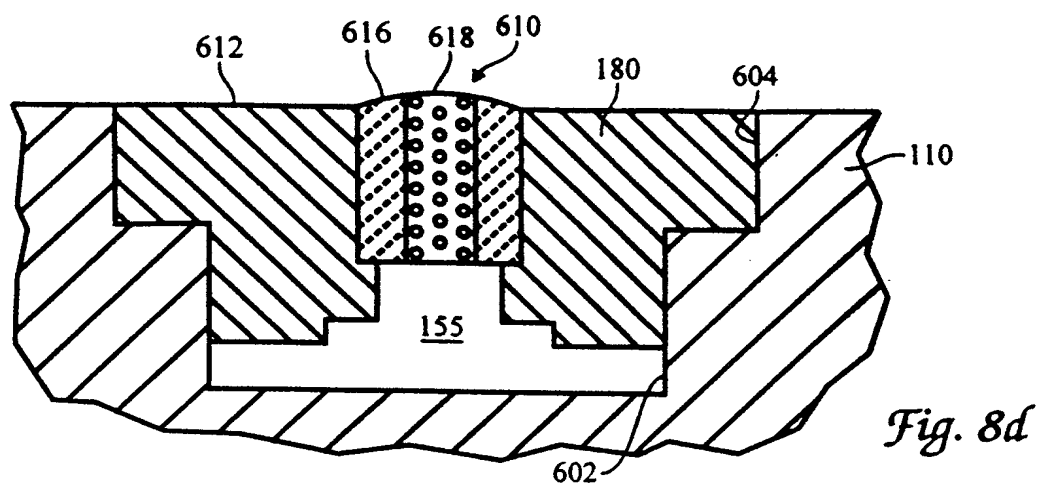


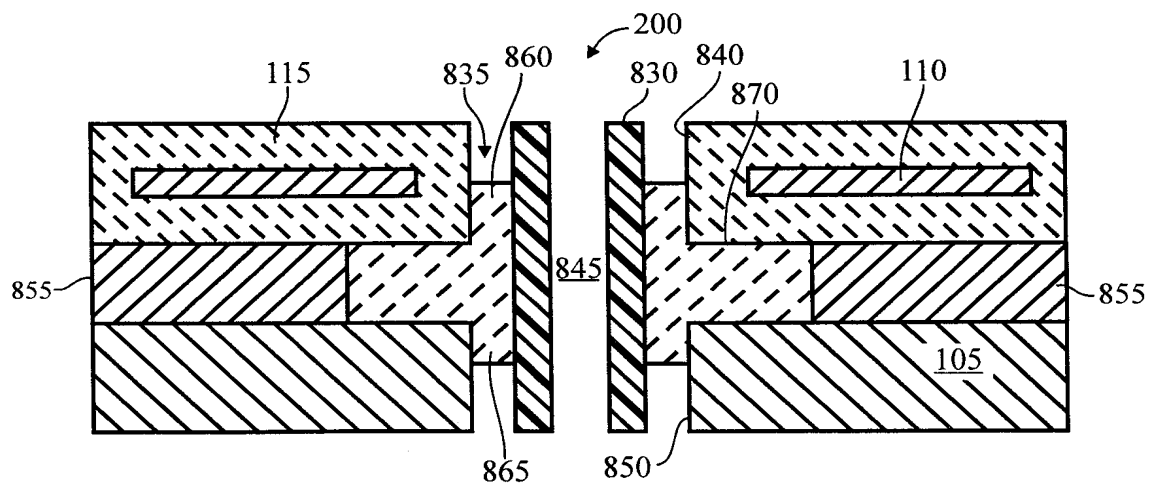
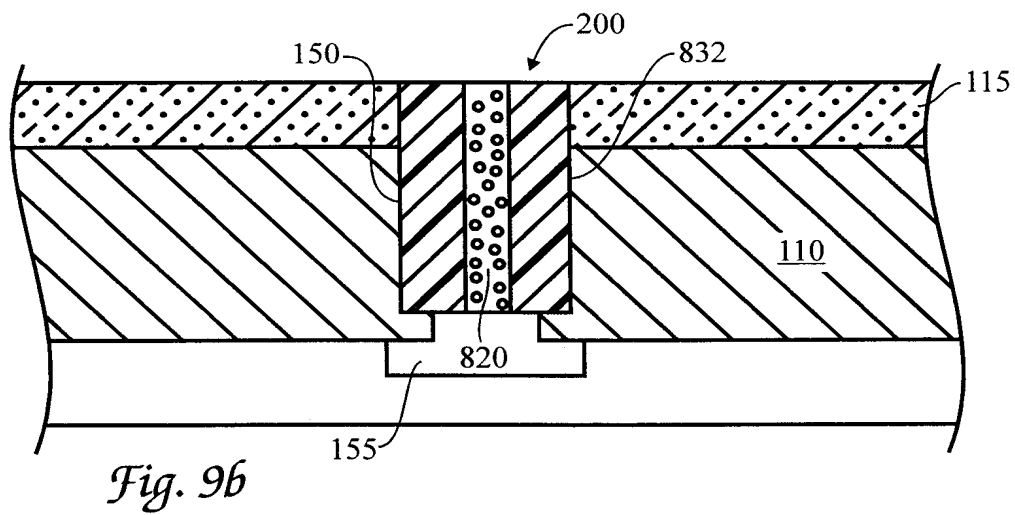
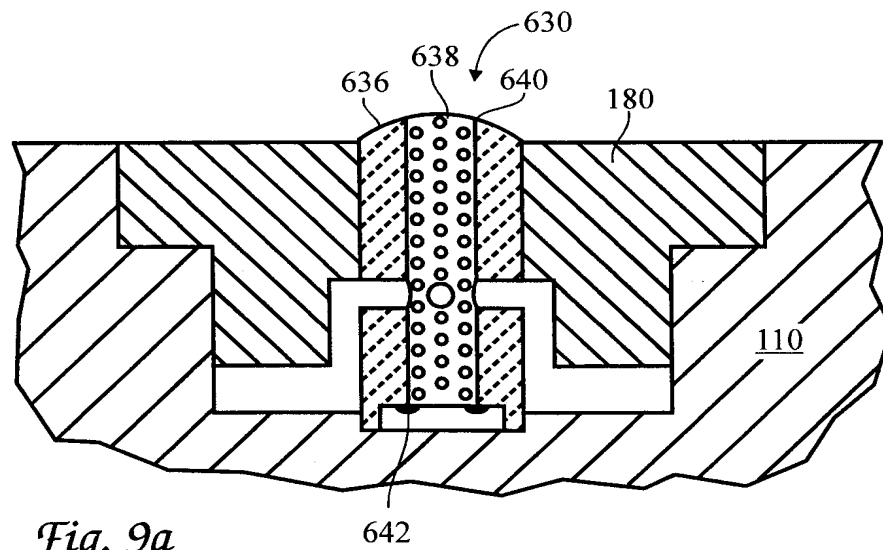
Fig. 4b



*Fig. 6**Fig. 7*







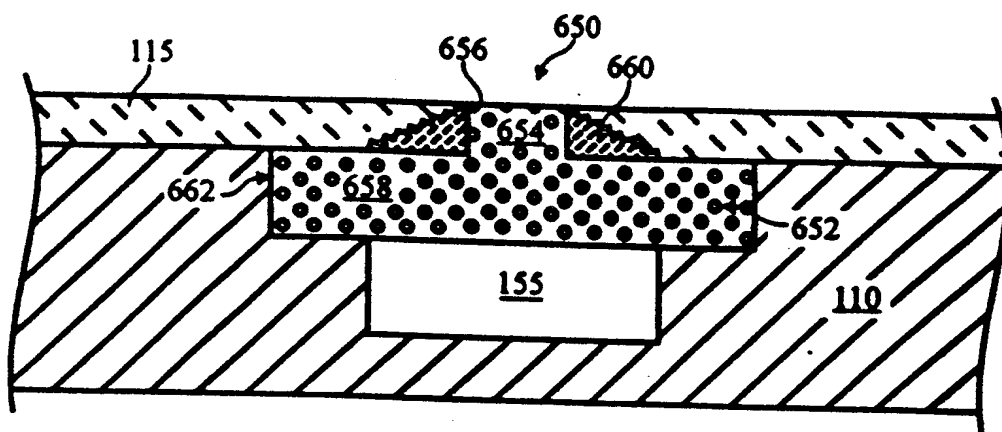


Fig. 10a

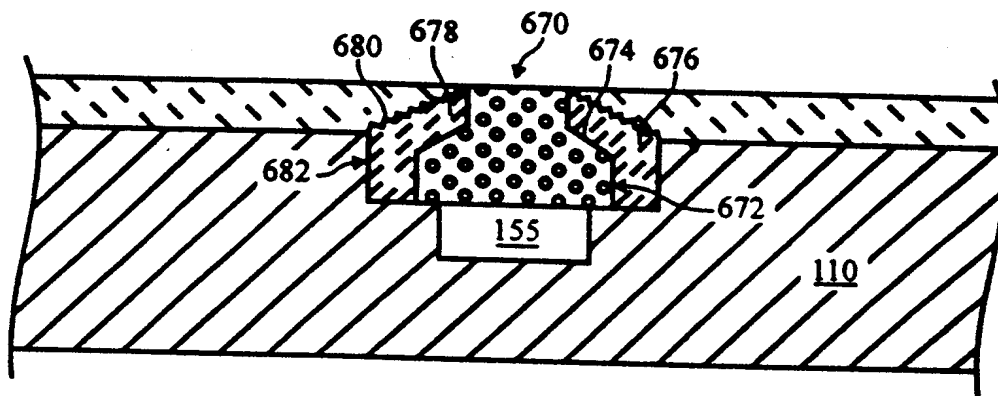


Fig. 10b

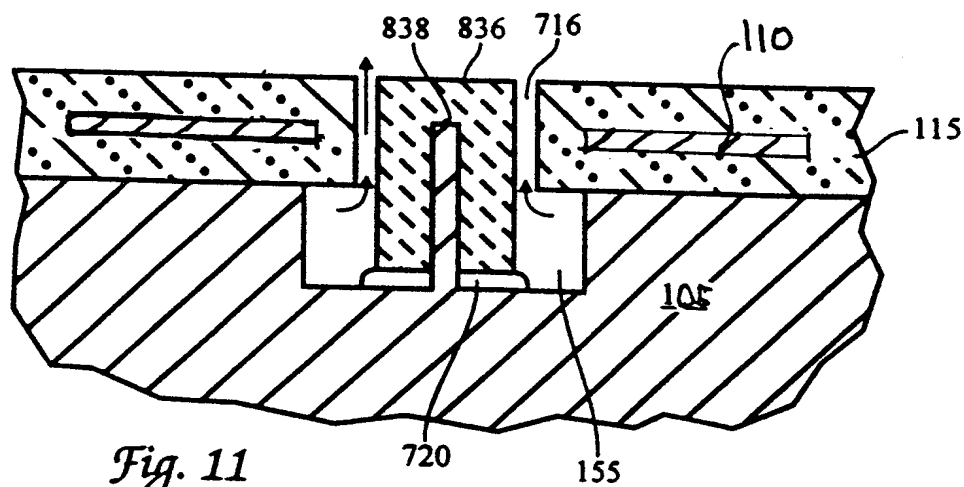


Fig. 11

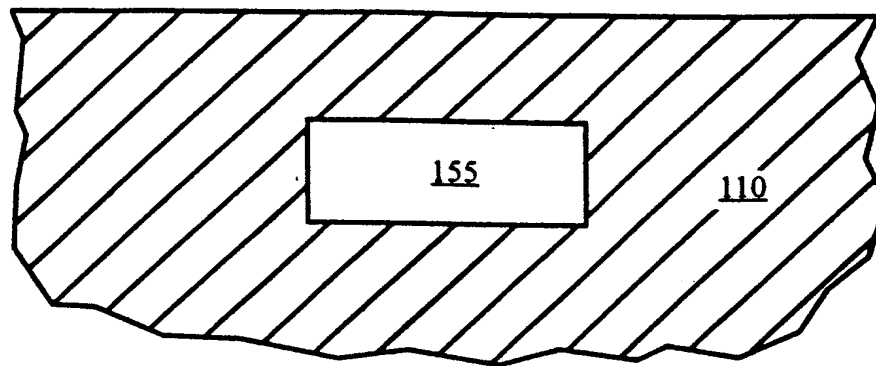


Fig. 12a

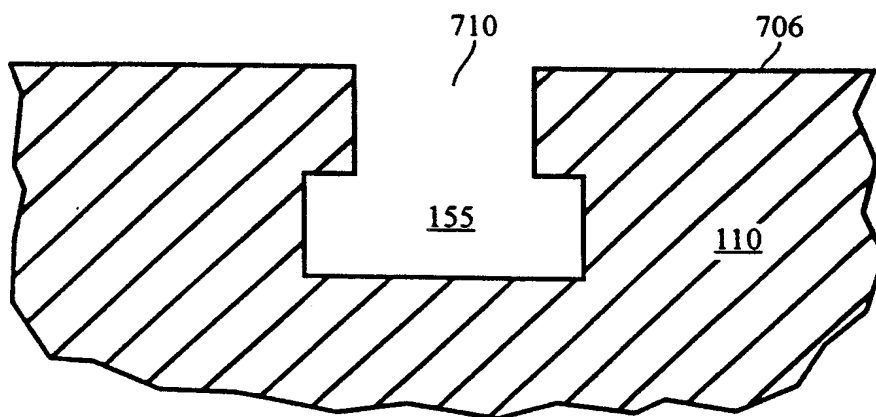


Fig. 12b

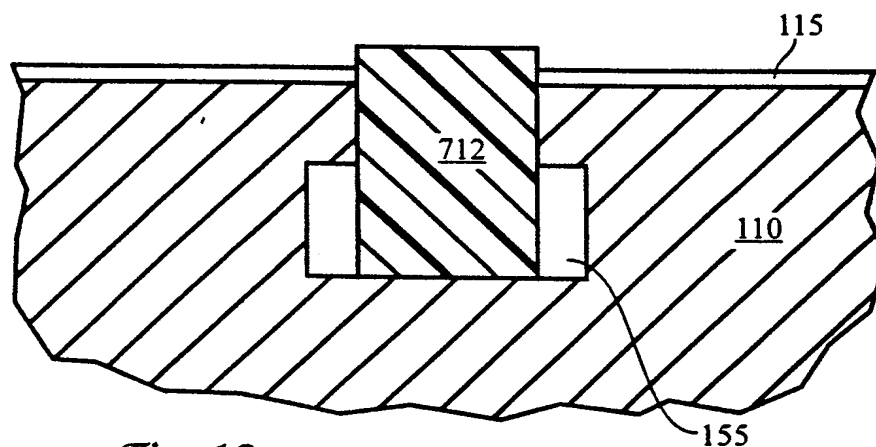


Fig. 12c

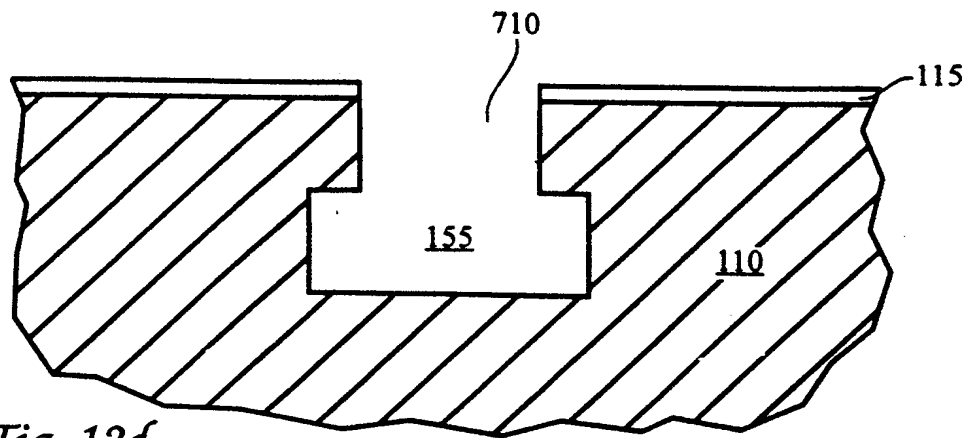


Fig. 12d

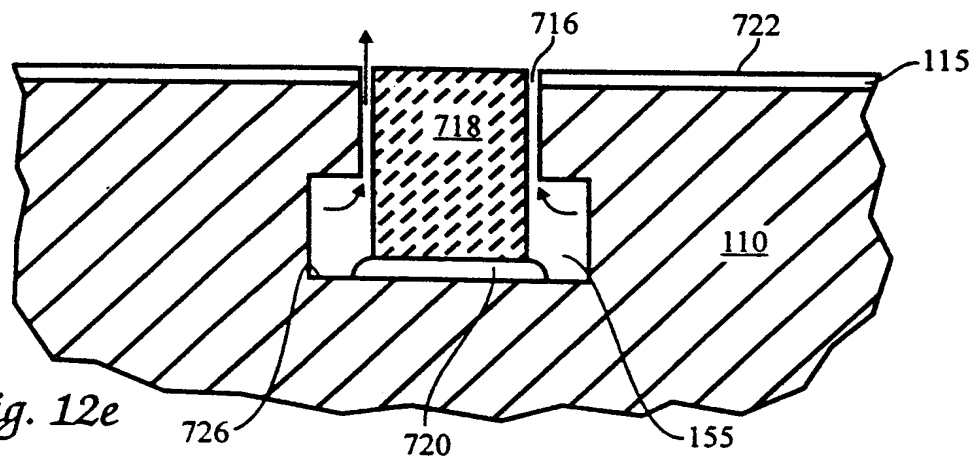


Fig. 12e

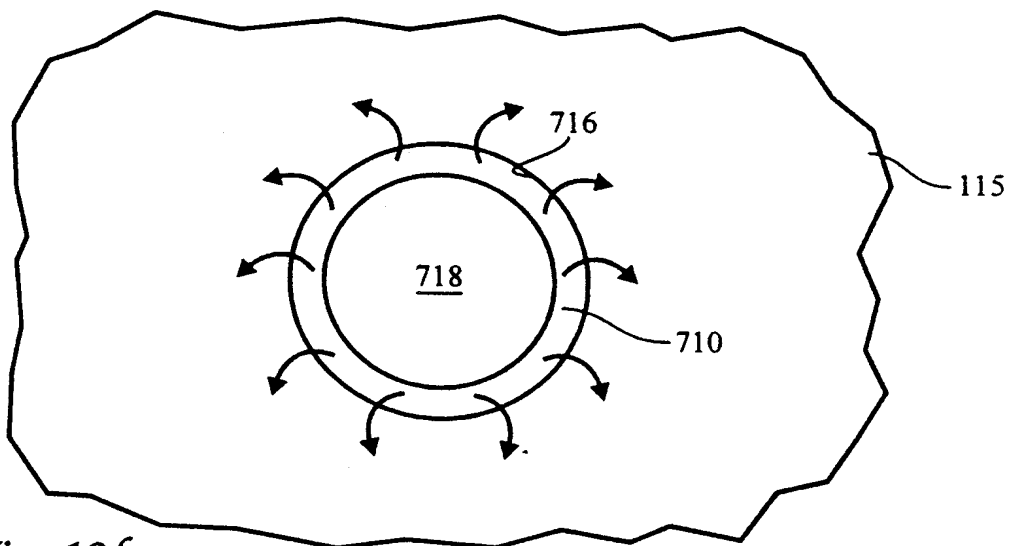
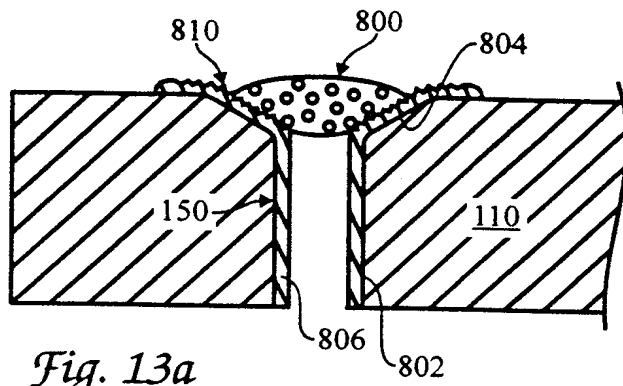
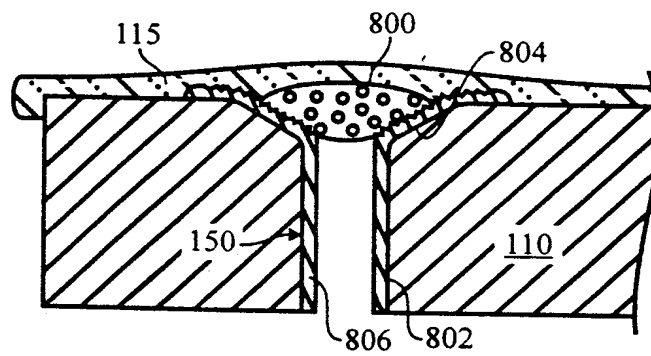
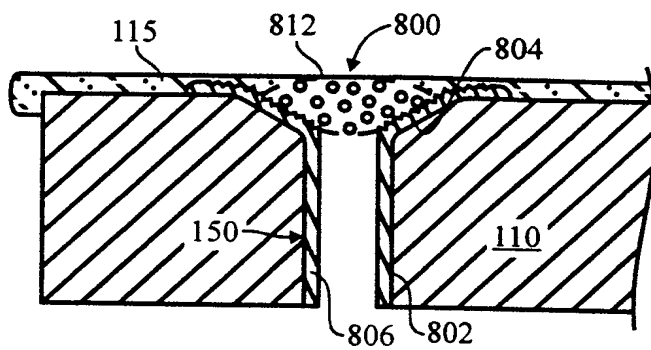
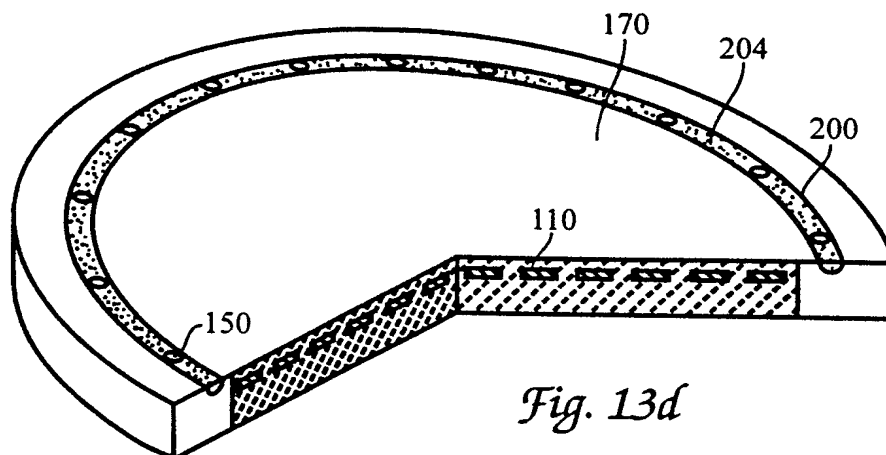
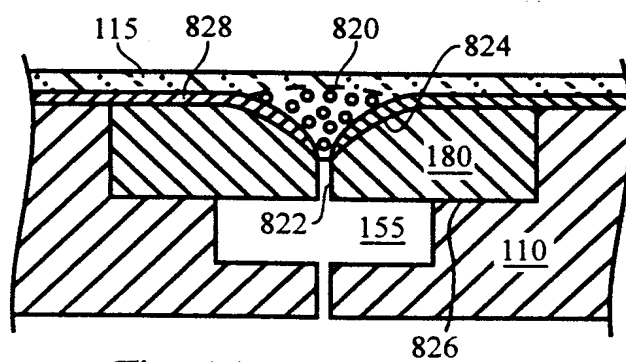
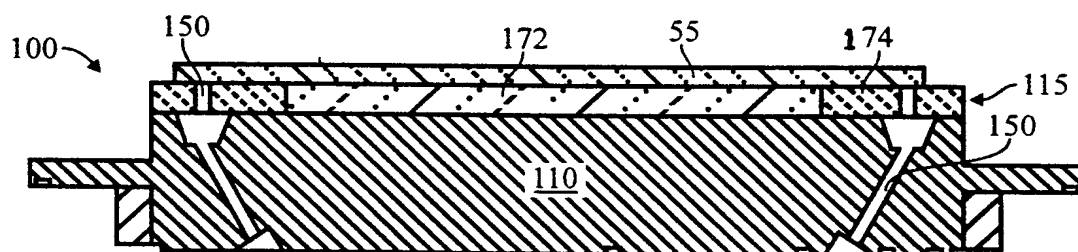


Fig. 12f

*Fig. 13a**Fig. 13b**Fig. 13c**Fig. 13d*

*Fig. 14**Fig. 15*

